Woods (Edward)

Consumption of Fuel &c

in

Locomotive and other Steam Engines.

Division A.—Locomotive Engines.

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OBSERVATIONS

ON

THE CONSUMPTION OF FUEL AND THE EVAPORATION OF WATER

IN LOCOMOTIVE AND OTHER STEAM ENGINES.

BY EDWARD WOODS, C. E.
LIVERPOOL.

The present Paper has for its object to present briefly some of the leading principles which regulate or influence the consumption of fuel in the steam engine,—to apply these principles to the case of the locomotive engine especially,—and, by way of illustration of the intimate dependence of practical results upon them, to state such facts, within the range of the writer's experience, as may be necessary to explain the successive steps by which a gradual but marked improvement in the condition of the locomotive engine, as respects its consumption of fuel, was attained in the course of years at the workshops and on the line of the Liverpool and Manchester Railway.

The immediate cause of motion in a steam engine, and of the force exerted by it on external matter, is the elastic force of steam. The chemical action of the elements brought together in the furnace must be regarded as the remote cause and original source of the forces which are manifested in the steam, and by its means are brought to bear on the piston of the engine.

In this point of view we may consider water, in its conversion from the fluid to the gaseous state, as a convenient depository and carrier of the forces developed in combustion, rather than as the generator of such forces, or as able in any way to add to or diminish from their quantity.

The forces resulting from chemical changes in the forms of matter may be manifested in other ways; as, for instance, in electro-magnetic phenomena and

in changes of the volume of gases; but in no way can we at present so readily avail ourselves of them as through the medium of steam.

The elements practically subjected to mutual action in the furnace are, carbon, or compounds of carbon and hydrogen, in a more or less pure state, and the oxygen of the atmosphere. The carbon and hydrogen, placed in contact with oxygen under certain conditions of temperature, undergo various transformations, and the products possess very different properties from the elements out of which they were formed. The process of combination,—combustion, as it is termed,—is attended with the disturbance of the forces under which the equilibrium of the molecules of the burning body is maintained, and is accompanied by the generation of heat.

There is a strong presumption for the existence of a *constant relation between the weight of the substance consumed and the heat it generates;* and there is also ground for the belief that *any definite amount of heat is convertible into, and can be expressed by, an equivalent of mechanical force.* We shall consider these two propositions separately.

RELATION BETWEEN THE WEIGHT OF FUEL AND THE HEAT WHICH IT GENERATES.

The problem of measuring the heat evolved in the combination of bodies is one of essential importance in connection with many of the arts of life, and has accordingly received the attention of distinguished scientific men. Count Rumford, Crawford, Watt, Black, Lavoisier, Dalton, M. Despretz, M. Dulong, M. Hess, M. Arago, Bezelius, Dr. Ure, are amongst the names of those who have devoted themselves to the inquiry. The results of the earlier experiments must be regarded as approximations towards the more precise data which have been within the last few years obtained; and the conclusions derived by the first labourers in this branch of science have consequently undergone considerable modification.

The experiments of M. Dulong, and of others subsequently, especially those of M. Hess, and of Dr. Andrews of Belfast, appear to have been conducted with the greatest accuracy, and with those precautions, as regards the arrangement of the apparatus, the mode of manipulation, and the reduction of the observations, which are indispensable to insure correct and consistent results.

These experiments may be considered as establishing the following general conclusions.[1]

[1] See Phil. Mag. July, 1841: 'Summary of Discoveries on the Heating Powers of Bodies.'

The quantity of heat disengaged by different substances is very different.

Hydrogen, for instance, produces about four times the heat derived from an equal weight of carbon, and fourteen times the heat from an equal weight of sulphur, in the act of combining with oxygen. The observations of the earlier inquirers, including some by Despretz, indicated a constant relation between the weight of oxygen which entered into combination with the burning fuel and the heat that was evolved; in other words, that a pound of oxygen would generate in each case the same quantity of heat, whether in combining with hydrogen, carbon, alcohol, ether, or other combustibles. This conclusion, which would not be inconsistent with the law expressed, inasmuch as the combining proportions of oxygen and combustible bodies differ greatly for different bodies, is, however, not supported by later experiments.

The quantities of heat evolved are (nearly) the same for the same substance, no matter at what temperature it burns.

From this law it follows that the *rate* at which combustion may proceed does not affect the quantity of heat produced by a given weight of fuel. The rate of combustion is proportional to the temperature excited, and to the supply of oxygen delivered. A pound of carbon generates precisely the same quantity of heat, whether it is burnt with rapidity in an intensely heated furnace, under the influence of a powerful blast, or whether it is consumed slowly in an Arnott's stove wherein the supply of oxygen is purposely limited, in order to moderate the intensity of the heat, and prolong the duration of the effect.

Some engineers have believed that the greatest economy in fuel is obtained in cases of very slow combustion, and this mode of applying heat has been adopted with apparent advantage in the so-called 'Cornish boilers;' but if the fact be so, for which reasonable doubt exists, the cause is owing partly to the retention of the heat for a longer time in the spaces around the boiler, and thereby increasing the ratio of the heat absorbed by the boiler to the heat which escapes up the chimney; and partly, perhaps, also, with certain descriptions of coal, to their inability to withstand an intense heat very suddenly applied without undergoing a change of form which is unfavourable to a complete combustion.

The quantities of heat evolved by carbon and hydrogen, as ascertained by Dr. Andrews,[2] whose results accord very closely with those of M. Dulong, are as follows:

1 gramme carbon evolves	7900	(French) units of heat.
1 gramme hydrogen ,,	33808	ditto.

The unit they adopt is the amount of heat required to raise, through one degree

[2] Phil. Mag. Aug. Sept. 1844.

centigrade, one gramme of water at the temperature at which the experiment is performed.[3]

Reducing the results to English weights and measures, and taking the unit as the amount of heat required to raise through one degree Fahrenheit one avoirdupoise pound of water at the temperature of the experiments, we find that in combining with oxygen—

1 pound of carbon . . .	evolves	14220 (English)	units of heat.
1 do. of hydrogen . .	„	60854	do.

These amounts of heat, applied to the evaporation of water already raised to the temperature of 212° Fahrenheit, assuming that the latent heat of steam of the same temperature is 972°, would produce the following effects:

1 pound of carbon	will evaporate	14·6	pounds water from 212° Fahr.
1 do. of hydrogen	„	62·6	do.[4]

These numbers may be therefore taken to express the highest[5] duty which the above-named elementary substances, in their purest state, can possibly accomplish, supposing the entire heat disengaged to be communicated to the water, and none lost by external radiation and conduction.

The duty expressed by the above numbers we shall term the 'theoretical' duty of the fuel in evolving heat, not using the word to denote an effect not yet ascertained in fact, but by way of contrast to the effective working duty of fuel as used in common practice.

It is almost superfluous to state that the necessary conditions for obtaining

[3] *Table of Results of Dr. Andrews' Experiments on other Substances.* (*Phil. Mag. Aug. Sept.* 1844.)

1 gramme	carbonic oxide	evolves	2431	units of heat.
1 do.	marsh gas	„	13108	do.
1 do.	olefiant gas	„	11942	do.
1 do.	alcohol (sp. gr. 0·7959) at 59° Fahrenheit	„	6850	do.
1 do.	sulphur	„	2307	do.
1 do.	phosphorus	„	5747	do.
1 do.	zinc	„	1301	do.

1 gramme (French) = ·00220606 ℔s. avoirdupoise.
100 degrees centigrade = 180 degrees Fahrenheit.

[4] 14220 units ÷ 972° = 14·6.
60854 do. ÷ 972° = 62·6.

[5] The second measure of heat, here adopted, is a common and convenient one; but it may be necessary to explain that it supposes the heat imparted to the water to be directly and entirely carried off in the steam, and lost, and by no means involves the proposition, that under certain other circumstances,—as for instance when the heat of steam evaporated in one stage of the process is applied to the evaporation of water in a subsequent stage,—the duty of fuel cannot be increased beyond the numbers here given.

the 'theoretical' duty, whether as regards the purity of the fuel and the prevention of extraneous dispersion of heat, can only be fulfilled approximately; but it is nevertheless important to know the ultimate limit of duty, in order to be able to compare it with the actual working duty in each case of the application of fuel in the furnace. The difference will render manifest the amount by which the working duty falls short of the theoretical, and the proportion between the one and the other will be the true measure of the degree of perfection attained in any given boiler and furnace.

The heat evolved in the combustion of certain of the compound gases is the same (nearly) as that evolved in the combustion of their constituents separately.

This law[6] holds good in regard to the gases compounded of carbon and hydrogen. Such, in fact, are the gases distilled from bituminous coal when exposed to a red heat. Let us apply the law to the cases of light carburetted hydrogen and olefiant gas.

Light carburetted hydrogen is composed of

Carbon	1 equivalent;	weight	=	6·12
Hydrogen	2 do.	do.	=	2·00
Light carb. hydrogen .	1 equivalent;	weight	=	8·12

Supposing the elements to be burnt separately,

The carbon would produce	48348	units heat	= 7900 × 6·12
The hydrogen ,,	67616	do.	= 33808 × 2
	115964	do.	

which number, divided by the weight 8·12, gives a quotient of 14281 units of heat for each gramme of the compound.

The heat resulting from the combustion of light carburetted hydrogen is in fact (see Table, page 4) 13108 units.

In the case of olefiant gas the agreement is closer. Olefiant gas is composed of

Carbon . . .	4 equivalents;	weight	24·48
Hydrogen . .	4 do.	do.	4·00
Olefiant gas . .	1 do.	do.	28·48

Supposing the elements to be burnt separately,

[6] The correspondence may be conceived to be the closest when the constituent gases, in combining, neither set free nor bind any heat.

The carbon would produce		193392	units of heat.
The hydrogen	,,	135232	do.
		328624	do.

which number, divided by the weight 28·48, gives a quotient of 11539 units of heat for each gramme of the compound.

The combustion of 1 gramme of olefiant gas produces (see Table, page 4) 11942 units of heat.

From the above considerations it would at first sight appear probable that the heating duty of fuel is equal (nearly) to the sum of the separate duties of its constituent combustible elements, supposing these to be fully oxidized; and that when the composition of any given coal or coke is known, its theoretical value in generating heat could be assigned accordingly. But it so happens that the elements out of which the gaseous combustible products of coal are formed exist in coal in the solid state, and require for their conversion into the gaseous state, and before they are in the condition themselves to burn and evolve heat, a large quantity of heat derived from the previous combustion of other parts of the fuel. The quantity of heat thus abstracted has never been accurately ascertained, but is supposed, on a rough computation, to amount to little less than the heat afterwards evolved in the combustion of the gas. It has accordingly been often remarked that those coals which contain the least gas are practically the strongest.

In the absence of direct experiment, we are perhaps not justified in assuming that the heating value of any description of coal containing hydrogen exceeds that of the carbon it contains.

Upon this assumption, the following rule for the heating value of fuel will apply:

Multiply the weight (in lbs.) of carbon in the fuel by 14·6, and divide the product by the weight of the fuel in lbs.; the quotient is the theoretical heating power of 1 lb. of the fuel.

Thus for instance, to take the best Newcastle caking coal, which on an average of specimens was found by Mr. Richardson (see Phil. Mag. 1838, vol. xiii. p. 121).

88·	carbon.
5·2	hydrogen.
5·4	azote and oxygen.
1·4	ashes.
100·0	

Carbon 88 × 14·6 = 1284·8

Theoretical duty of 1 lb. of dry coal is equal to 12·84 lbs. water evaporated from 212° Fahrenheit.

When it is considered that even in the same mines the quality of the coal varies materially, and that, comparing the bituminous coals obtained from different mines, the proportion of carbon ranges from 60, or even less, to 88 per cent., and the quantity of ashes from 1 to 15 per cent. and upwards, it is obvious that no constant expression of the value can be assumed, but that it is necessary in each case to ascertain the specific composition and assign the duty.

We shall hereafter inquire how far the theoretical and working duties differ, and explain some of the causes of the difference.

RELATION BETWEEN MECHANICAL FORCE AND THE HEAT WHICH PRODUCES IT.

One of the most important and interesting inquiries relative to the steam engine is that which traces the connection between the heat expended and the force produced.

The method of separate condensation discovered by Watt,—the application by Woolf and Hornblower of the force of expanding steam,—occasioned an important change in the relation of heat to power, and increased in a remarkable manner the dynamical value of fuel.

There are no sufficient grounds for concluding that the improvements in the steam engine subsequently made, and extending even down to the present time, have reached the highest point of the scale. On the contrary, there is strong evidence of the existence of a margin in the field of economy, in the working duty of fuel, ample enough to occupy the husbandry of many labourers for some time to come, and holding out the prospect of a good return.

The recent inquiries of some scientific men, whose attention has been engaged on the subject of the relation between heat and the mechanical effects it produces, have resulted in the discovery of the principle, that the *action of a given amount of heat may be represented by a constant mechanical work performed;* that is to say, by the elevation of a determinate weight through a determinate height.

This constant of work for the unit of heat has been termed '*the mechanical equivalent of heat*,' and expresses the maximum limit of duty which, on the assumption of the truth of the above-named principle, that unit of heat can possibly perform.

It has been shown that, through whatever medium or carrier the mechanical work of heat may be developed or conveyed, whether by means of the vapour of water or other liquids, or by means of atmospheric air or other gaseous matter, the same amount of work is invariably the result.

This constant of work is many times greater than the work hitherto obtained from the best condensing expansive engines.

M. Clapeyron, in his treatise on the moving power of heat, and M. Holtzmann of Manheim, who availed himself of the labours of M. Clapeyron and M. Carnot in the same field, grounding their investigations on the received laws of Boyle or Marriotte, and Gay-Lussac, which express the observed relation of heat, tension, and volume in steam and other gaseous matter, have by theoretical inquiry arrived at the conclusion that—

The mechanical equivalent of the quantity of heat capable of increasing the temperature of 1 lb. of water by one degree of Fahrenheit's scale is a mechanical force capable of raising a weight, between the limits of 626 lbs. and 782 lbs., one foot high.

Mr. Joule, of Manchester, proceeding by entirely different, and independent, and in fact purely experimental methods, concludes that the mechanical equivalent of heat may be taken at 782 lbs. raised one foot.

The mode of investigation pursued by the continental philosophers, especially by M. Holtzmann,[7] may be thus briefly explained.

They suppose a given weight of steam, or gaseous matter, to be contained in a vertical cylinder formed of non-conducting material, in which is fitted an air-tight but freely moving piston. This piston is pressed downwards by a weight equal to the pressure or tension of the steam or gas. The weight, initial temperature, pressure, and volume being known, a definite quantity of heat from without is supposed to be imparted to the vapour.

The result will be partly an elevation of the temperature of the vapour, and partly an increase of volume, or, in other words, a motion of matter, the pressure or tension remaining the same.

But the result may be represented simply and solely by a motion of the matter (dilatation). For this purpose it is only necessary to allow the vapour to dilate without any loss of its original or imparted heat until it re-acquires its initial temperature.

In this case the final effect is simply dilatation of the vapour under the subsisting pressure; and the mechanical work done is represented by the product of that pressure into the space through which it has been made to recede.

Mr. Joule's estimate of the mechanical equivalent of heat is derived from three distinct classes of experiments.

1st. From the calorific effects of magneto-electricity. (Phil. Mag. 1843, vol. xxiii. p. 263.)

This method is to revolve a small compound electro-magnet, immersed in a glass vessel containing water, between the poles of a powerful magnet; to measure

[7] 'Über die Wärme und Elasticität der Gase und Dämpfe.' Von C. Holtzmann. Manheim, 1845.

the electricity thence arising by an accurate galvanometer; to ascertain the calorific effect of the coil of the electro-magnet by the change of temperature in the water surrounding it. Heat is proved to be *generated* by the machine, and its mechanical effect is measured by the motion of such weights as by their descent are sufficient to keep the machine in motion at any assigned velocity.

2ndly. From the changes of temperature produced by the rarefaction and condensation of air. (Phil. Mag. 1845, vol. xxvi. p. 369.)

In this case, the mechanical force producing compression being known, the heat resulting was measured by observing the changes of temperature of the water in which the condensing apparatus was immersed.

3rdly. From the heat evolved by the friction of fluids. (Phil. Mag. 1847, vol. xxxi. p. 173.)

A brass paddle-wheel, in a copper can containing the fluid, was made to revolve by descending weights. Sperm oil and water as the fluids gave the same result.

The mechanical equivalent of the unit of heat was—

As assigned by the	1st method,	838 ℔s.	raised 1 foot.
,,	2nd do.	795 ℔s.	do.
,,	3rd do.	782 ℔s.	do.

Mr. Joule considers the last method as likely to give a more accurate result than either of the two former; and it is remarkable that the equivalent given by the 3rd method, viz. 782 ℔s., should be identical with the major limit assigned by Holtzmann.

We shall, however, prefer to take the mean adopted by Holtzmann, and to consider THE MECHANICAL EQUIVALENT OF THE UNIT OF HEAT as represented by a WEIGHT OF 682 ℔s. LIFTED ONE FOOT HIGH; the unit of heat being the quantity required to raise the temperature of a pound avoirdupoise of water one degree Fahrenheit.

THE WORKING DUTY OF FUEL AS REGARDS THE PRODUCTION OF STEAM.

It has been shown that the amounts of heat obtainable from carbon and hydrogen respectively are such as in the case of the combustion of

1 ℔. of carbon would suffice to evaporate 14·6 ℔s. of water from 212°;

and in that of the combustion of

1 ℔. of hydrogen would suffice to evaporate 62·6 ℔s. of water from 212°;

but that the effect of any heat given out by the combustion of the hydrogen is in great measure neutralized by the absorption of heat necessary to volatilize the

hydrogen; and it has been observed that such results are not attainable in practice, in consequence of the diversion of the heat evolved into other channels than those which conduct it directly into the water. To this may be added, that in the common instances of so-called combustion, the combustion is only partial, a portion of the fuel being dissipated without undergoing combustion at all.

Whatever difference may be found practically to exist between the actual and the theoretical duty of the fuel consumed under any given boiler, or given system of firing, may be assigned to one or other of the above causes; and in the comparison of different boilers or modes of firing, the *amounts* of difference, as expressed by the *ratios* between the actual and theoretical duties, would constitute a scale by which the commercial value of any particular apparatus or system of firing can be tested.

In the *Cornish boiler* a duty equal to 10·29 ℔s.[8] water, evaporated from the temperature of 212°, has been obtained from 1 ℔. of coal.

In the *cylindrical* boilers used in the manufacturing district of Manchester the duty does not appear to exceed 7 ℔s. water evaporated from 212° by 1 ℔. of coal.

In the *locomotive* boiler it has been found, on the average of an extensive series of experiments on the engines of the Liverpool and Manchester Railway, that the duty of 1 ℔. of Hulton or Worsley coke is equal to the evaporation of $8\frac{1}{2}$ ℔s. water from the temperature of 212°.

In the larger engines of the Great Western Railway nearly the same duty is obtained. Mr. Gooch[9] states that their last constructed engines (the area of tube surface being from ten to eleven times the area of the fire-box) evaporate 8 to $9\frac{1}{2}$ ℔s. water with 1 ℔. of coke, according to the rapidity of evaporation; the slowest evaporation with a given sized boiler producing the best result.

The variation in the heating quality of different descriptions of coke from different mines is often very great. In Lancashire the Hulton and Worsley cokes rank highest. Representing the duty of these by 100, it was found by trial that the duty of cokes from six other mines was represented by the following numbers: $76\frac{3}{10}$, $80\frac{3}{10}$, $80\frac{3}{10}$, $81\frac{7}{10}$, 89, $90\frac{1}{10}$. In some instances the inferior duty was partly occasioned by the tenderness of the coke, or inability to withstand the action of the blast; the large pieces breaking up into small ones, and these either falling through the bars or being carried off by the draft.

The above general results in the three most important classes of steam engine boilers will serve to show that considerable loss of heat takes place in each case.

[8] Report on the Coals suited to the Steam Navy. By Sir H. De La Beche and Dr. Lyon Playfair.

[9] 'Report of Commissioners of Railways respecting Railway Communication between London and Birmingham,' 1848, p. 57.

It does not, however, appear likely that the locomotive boiler can be pushed to perform a much higher duty, taking into account the mechanical limits imposed in its construction. But there is no sufficient reason, except in so far as the comparative cost of alterations and that of anticipated saving in fuel may influence the owner of the boiler in incurring an immediate expense, why the performances of the majority of stationary engine boilers should not be materially improved.

We proceed to consider briefly the circumstances which occasion a diversion of a portion of the heat generated, and dissipation of part of the fuel unconsumed.

Diversion of heat generated.

This may be ascribed chiefly to one or other of the following causes:

1. *Vaporization of the hygrometric water.*

Coal in the state in which it is obtained from the mine contains from 1 to 2 per cent. of water: when exposed to the atmosphere, and especially to rain, it of course imbibes a further quantity, which is greater or less in proportion to the moisture of the air and to the size of the particles of coal; the smaller kinds, and especially what is termed slack, being more retentive than the round coal. This water must be converted into vapour before combustion takes place, and the heat necessary for its conversion must be derived from other portions of fuel undergoing combustion, and is consequently not communicated to the boiler.

Coke being of a much more porous or spongy texture than coal, absorbs frequently as much as 7 per cent. of water in its passage from the oven to the place of consumption in uncovered waggons. A difference in the hygrometric state of the atmosphere has a marked and rapid effect on the amount of hygrometric moisture in coke. Upon accurate weighing, it was found that a quantity of coke delivered in rainy weather, and afterwards exposed for a few days to a drying wind, was reduced from 388 cwt. to 360 cwt. Hence will be seen the advantage of keeping the coke dry until the time it is actually put into the furnace; for not only is there in damp fuel a less quantity of combustible matter than is paid for, unless due allowance be expressly made, but there is a positive reduction of effective power in the combustible portion itself.

Thus to take the instance cited of coke with 7 per cent. of moisture:

100 lbs. of such coke contains 93 lbs. dry fuel.
7 lbs. water.
100

The 93 lbs. dry coke are competent in practice to evaporate $8\frac{1}{2}$ times its weight of water . .	= 790 lbs.
But 7 lbs. water contained in the fuel must first be evaporated	= 7 lbs.
There remains, therefore, as the effective quantity of water evaporated by 100 lbs. of damp fuel,	783 lbs.

Whereas 100 lbs. dry coke evaporate 850 lbs. water.

This is equal to a diminution of effective duty in the proportion of 850 to 783, or about 8 per cent.

In every contract for the supply of coke it is advisable that the contractor should be bound to send it in closed waggons, or waggons covered with water-proof sheets; and the coke dépôts should be so constructed that the waggons may be unsheeted, and the coke weighed out and stocked under cover.

2. *Production of such elevation of the temperature of the air or gases in the chimney as may be required to obtain the draft.*

In the fixed engine furnace the necessary draft is maintained by the differential pressure, as between a column of heated and rarefied air in the chimney-stalk and a column of the colder air without, of equal area and height; the difference of temperature being maintained by the constant accession of heated gaseous matter to the contents of the chimney, which are constantly discharging themselves from the top. It should be the object to render this loss of heat a minimum. The quantity of heat carried off is directly proportional to the quantity of gaseous matter which escapes from the flue into the chimney, and to the temperature at which it escapes. The quantity is a minimum when, for the combustion of any given weight of fuel, no more air has been allowed to pass through the furnace than suffices fully to oxidize the elements of the fuel; and the temperature is a minimum when it does not exceed, unless by a few degrees, the temperature at which the water is being converted into steam of the assigned pressure. When the fire is contained in a box surrounded by water to be heated, as in a locomotive engine, the grate-bar frame should be made to fit closely to the sides of the box; otherwise the surface of the plates adjoining will be insulated from the action of the fire by a stream of cold air rushing upwards between the frame and the box,—a frequent source of waste of fuel.

In the case of the locomotive engine, the draft is obtained mechanically by the application of the steam already generated; and its intensity is liable to considerable variation under differences of pressure in the cylinders, and differences of velocity of the piston.

The current of heated air through the tubes may be made to become so rapid as not to afford the necessary *time* for imparting all the heat which under a milder draft would be taken up by the absorbent surfaces, and a quantity of surplus heat is carried to waste up the chimney.

In former years the draft in the locomotive engine was solely obtained by the action of the blast-pipe. The introduction of the 'close ash-pan,' that is to say, an ash-pan closed below and on all sides except the front, the front being left open to receive a rush of air produced by the velocity of the train, has had the effect of relieving the blast-pipe from a part of its duty, and of saving steam

and fuel to that extent. It is however to be observed, that the saving is less on lines of undulating gradients than on those in which a *constant* tension on the fire is needed; for whilst the engine is descending a gradient with steam cut off, it is obviously desirable to stop the passage of air through the fire: but the present form of ash-pan prevents this from being entirely done, and there is a certain waste of fuel on descending gradients to set against the saving on other parts of the road where artificial power is required. The remedy would be to have some ready and simple means of controlling the admission of air: if such means were provided, both before and behind the ash-pan, the engine would generate steam equally well, whether running backwards or forwards.

3. *Conduction through solids composing the furnace and boiler, and radiation from the same.*

The greater economy of fuel obtained in the Cornish boilers appears in great measure to arise from close attention to this point; these boilers and furnaces being, in fact, buried in a mass of badly conducting material, such as ashes, brickwork, &c.

The locomotive boiler is particularly exposed to loss of heat from this cause, almost every part being in rapid motion through and in constant contact with the atmosphere, a thin layer of imperfectly conducting material only intervening. It is usual to clothe the boilers with a layer of felt, then with boards, and over them a thin casing of zinc or oil-cloth stretched tightly, painted and varnished to turn off the wet. The high temperature of the steam acting through the boiler-plate often converts the felt or inner surface of the wooden boards into charcoal, which is a still inferior conductor. Notwithstanding these precautions, there is some radiation and waste of heat.

In outside-cylinder engines, the cylinders are unavoidably placed in a position calculated to cool their surfaces and diminish the pressure of the steam within, in which respect they work to some disadvantage as compared with inside-cylinder engines, which have their cylinders enclosed in the hot smoke-box.

4. *Dispersion of heated water by priming and leakage.*

This water, suspended mechanically in the steam, and passing with it by the force of the current along the pipes and through the cylinders, without producing any dynamical effect, abstracts as much heat as was expended in raising its temperature from that of the feed-water to the temperature of the issuing steam. The quantity of water, and consequently of heat, thus carried off is dependent chiefly on the incidental circumstances of the purity of the water used, that is to say, its freedom from mud or greasy matter, and of the steam room given above the surface of the boiling water. The steam room in locomotive boilers being necessarily somewhat more contracted than in fixed engine boilers, and

the rate of evaporation in respect of the size of the boiler being much greater, there is more tendency to loss of heat from this source.

The best preventive of this loss consists in properly blowing off and cleansing the boilers at prescribed intervals, and in attention to the purity of the feed-water supplied. With these precautions the loss in a well-constructed boiler, with properly arranged steam dome and steam pipes, becomes very trifling, and scarcely appreciable.

Leakages in boilers are often occasioned by the unequal expansion of parts unequally heated, or of parts formed of different metals whose rate of expansion under equal increments of temperature differs; and such leakages are apt especially to occur after sudden and great variations of temperature, as in boilers after being blown off. Instances are well known in which from such causes a whole set of tubes has suddenly begun to leak.

Dissipation of unconsumed Fuel.

In every furnace a certain amount of heat is lost in two ways; first, by an absolute loss of unburnt substance of the fuel, which may be termed a mechanical loss, inasmuch as it proceeds from circumstances connected with the physical condition of the coal, or from imperfection in the mechanical apparatus of the furnace; and, secondly, by the incomplete combustion of the elements into which the fuel has been resolved by heat. The latter has its origin in the want of due regard to the chemical relations of the combining elements.

1. *Mechanical dissipation of the fuel.*

Amongst the ashes which fall from the grate-bars of a furnace there is always present a quantity of unconsumed solid fuel. The quantity depends, other things being equal, on the practical relation between the total area of air spaces and the width between the bars. The area of fire-grate being given, the bars must be arranged so as to present the least possible impediment to the passage of air through the fuel, whilst, at the same time, they afford effectual support even to the smaller pieces. For this reason it is desirable to make the grate-bars as thin as the strength or durability of the material (cast or wrought iron) will allow, adding in depth to make up for deficiency in thickness. The spaces between the bars are adapted to the nature of the fuel. In the case of small coal and slack, the spaces must be more contracted than where rounder coal or coke is employed. Experience soon shows what is the best proportion.

For the best qualities of coke, in the locomotive furnace, the following proportions have been found, on the Liverpool and Manchester Railway, to work with the best effect:

Thickness of bars	$\frac{1}{2}$ inch.
Width of air spaces	1 ditto.

With these dimensions, the proportion borne by the entire area of air spaces to that of grate surface is as

67 : 100.

The thinner the bars, the more will the proportion be increased. Probably a bar less than $\frac{1}{2}$ an inch thick could not be made durable.[10] About $\frac{3}{4}$ inch is a common thickness for locomotive furnaces. With such bars, and 1-inch spaces between, the proportion of air space to total area of grate surface is as

57 to 100,

showing a reduction of 10 per cent. of air space as between $\frac{1}{2}$-inch and $\frac{3}{4}$-inch bars.

Hence the rate of evaporation is diminished, or, if the air spaces be widened to compensate for the extra thickness of the bars, an attendant loss of fuel is incurred.

By proper management, this inconvenience and loss may in great measure be prevented. For this purpose it is only necessary to adapt the quality of the coke, with respect to its dimensions, to the particular duty it has to perform. Engines running with express or other quick passenger trains, and making few stoppages, require a maximum rate of evaporation which can be attained by feeding only with large round coke, thus allowing the air free access to the interior of the burning mass. The rule formerly practised on the Liverpool and Manchester line was to sort the coke from the waggons into three qualities by the rake. The first quality, or large round coke, was delivered to the passenger engines; the second quality, of an inferior size of round coke, to the luggage engines; and the third, of still less dimensions, to ballast engines. Thus the two latter classes of engines performed their work as efficiently as before, and the passenger engines obtained the benefit of the increase of speed which the first quality of coke afforded by increasing the rate of evaporation. The entire coke purchased was thus made to render effective service; for previously there had been much waste occasioned by the fire-men sorting it for themselves on the journey, and throwing out *onto* the road what they considered refuse.

Coke is frequently wasted from want of attention to the fixing of the fire-bars; for unless these are closely wedged or jammed into the frame which supports them, the rapid motion of the engine will cause an incessant friction upon the surface of the fuel at the bottom of the fire, and work a portion of it down into the ash-pan.

The power of fuel to resist mechanical dispersion in the furnace depends on its physical character.

Some kinds of coal contain water in a state of chemical combination, and are apt to split and fly to pieces when heat is applied. The anthracite coals of South

[10] With $\frac{1}{2}$-inch bars and 1-inch spaces, the destruction of fire-bars on the Liverpool and Manchester Railway, on a mileage of 320,000 miles, during the period extending from January 1st to November 10th, 1841, was 5 tons 16 cwt.; Hulton or Worsley coke alone being used.

Wales are peculiarly subject to this evil. In furnaces of the ordinary construction, and especially in locomotive boilers, it is difficult to use them, as they are apt to break down into powder under the influence of a strong heat suddenly applied. Other kinds, after long exposure to air and weather, appear to undergo a kind of incipient decomposition, which renders them tender and friable. Coke is rendered compact by the process of coking being long continued, producing thereby a sort of fusion between the particles. It is, of course, the manufacturer's interest to employ and replenish his ovens as quickly as possible, and it may therefore happen that the consumers are sometimes sufferers. To withstand the blast of a locomotive furnace, the coking process should be fully completed. Imperfectly coked coal is carried off like chaff through the tubes and up the chimney.

2. *Incomplete combustion of the elements of the fuel.*

Owing to an insufficient supply of air, the volatile products of coal frequently pass off unconsumed, or only partially so. The visible result is the formation of a cloud of smoke from what, before its admixture with air, was an almost invisible gas. This gas, or, at the least, the inflammable part of it, is a compound of carbon and hydrogen united in one or more definite proportions. If oxygen be presented to the gas at a time when its temperature is high enough for the forces of affinity to have full play, but in quantity insufficient to saturate the whole of the carbon and hydrogen, the hydrogen unites with the oxygen before the carbon is taken up, and the carbon is deposited, or rather separated, in the form of smoke.

It would be out of place here to refer to the subject of the prevention of smoke in furnaces, further than to state that a judicious application of the principle of a direct and well-regulated admixture of air with the heated gases, as they are distilled off from the fuel, appears not only to diminish very largely the quantity of smoke evolved from the furnace chimney, but also to effect some saving in fuel. According to Mr. Houldsworth's experiments, reported by Mr. Fairbairn in the 'Report of the British Association' (1844, page 109), an advantage of $12\frac{1}{2}$ per cent. was obtained on the average by the repeated admission of air through apertures behind the bridge. In some cases even a higher duty is said to have been observed.

The reason why the additional heat generated in the full combustion of the gaseous products falls short of the estimates held out by the advocates of different systems of smoke prevention, appears to be that the heat employed in volatilizing the gaseous products is nearly as great as the heat evolved in the subsequent combination of those products with oxygen.

A sufficient supply of oxygen is as important in the combustion of solid carbon as it is in that of the volatile parts of the coal; for it is well known that carbon unites with oxygen in two proportions, forming respectively carbonic oxide and carbonic acid gas.

Carbonic oxide contains	6·12 carbon + 8 oxygen = 14·12.
Carbonic acid contains	6·12 ditto + 16 ditto = 22·12.

To develope the full heat of which carbon is capable, it must receive the double dose of oxygen, and be converted into carbonic acid.

The fact of the generation and escape of large quantities of carbonic oxide from coke fires, especially where the mass of burning fuel is thick, is abundantly proved by experience. If the fire-door of the furnace of a locomotive boiler in full action be opened, a lambent blue flame is at once seen to surround the opening and play over the surface of the fuel, occasioned by the combustion of the carbonic oxide when the fresh air is presented to it. In like manner, a blue flame may occasionally be seen burning at the top of the chimney, the point where, supposing the furnace door to be shut, the heated carbonic oxide first meets a supply of oxygen. If the smoke-box be not quite air-tight, the outer plates have been known to become red-hot by the combustion going on within.

It may be useful to consider what loss of heat may arise as between the conversion of carbon into carbonic acid and of carbon into carbonic oxide. There are no direct means of ascertaining the loss or difference, inasmuch as no direct experiment can be made on the conversion of carbon into carbonic oxide *alone*. We may, however, arrive at a conclusion indirectly in the following way:

According to experiment, cited in the Table (page 4),

	Units of heat.
1 gramme carbonic oxide, in its conversion into carbonic acid, yields . . .	2431

Consequently

14·12 grammes of carbonic oxide will yield (2431 × 14·12)	34325

But 14·12 grammes carbonic oxide contain 6·12 grammes of carbon.

Therefore the 6·12 grammes of carbon, during the process of conversion from the state of carbonic oxide to that of carbonic acid, yield 34,325 units, equivalent to

	Units of heat.
1 gramme carbon, in its conversion from carbonic oxide to carbonic acid, yielding	5608

But according to experiment (see page 3),

1 gramme carbon, in its conversion from carbon into carbonic acid, yields . .	7900

The difference between the two last numbers indicates the heat developed by .

1 gramme carbon, in its conversion from carbon to carbonic oxide, . . =	2292

If this reasoning be correct, $\frac{5608}{7900}$ths, or, in round numbers, 70 per cent., of the heat which would be generated in the conversion of carbon to carbonic acid, is lost in the case of the conversion of the same weight of carbon into carbonic oxide only.

Every pound of carbon which escapes through the chimney in the form of

carbonic oxide carries off, therefore, as much fuel as would suffice to evaporate 10 lbs. of water from the temperature of 212°.

In the locomotive boiler, the remedy has been partially applied of perforating the fire-door with a number of small holes, and allowing the air to enter through them direct on to the top of the burning coke, from the surface of which the carbonic oxide is rising.

The various sources of waste hitherto detailed, however insignificant they may appear if considered singly, become, when combined together, of serious moment. This was fully evidenced in the saving of full 100 tons of coke per week, effected in the Liverpool and Manchester engines, in the autumn of 1839, in the following manner.

In the autumn of 1838 an account had been opened, against each engine, of the coke delivered, and weekly returns were made up of the general consumption. This served, to a certain extent, as a check, but the result was not so satisfactory as could have been desired. The returns might or might not give accurately the week's consumption. The coke was put loose in the tender, subjected to all the breakage to which its position rendered it liable, and being so placed, no account was taken of the stock remaining at the end of the week.

This might have been greater or less than the stock remaining at the end of the previous week. Hence an error in the week's consumption. Taking a longer period, of course the errors were neutralized, and a correct average obtained; but this was not sufficient. It was necessary to know not merely a month's consumption, nor a week's, but every day's consumption. Nay, it was found important that the drivers should know from hour to hour what they were using. Accordingly the system was changed. The coke, instead of being placed loose in the tenders, was put on in bags, each containing a certain weight, and every night, after the engines had finished work, the remaining ones were counted, and as many fresh ones put on as sufficed to make up a given complement. The driver was not permitted to empty his sacks before he actually wanted to feed his fire, and therefore no waste or breakage could take place. At the same time orders were given to let the fires burn low as the end of the journey was approached, for the purpose of diminishing waste during the intervals of rest.

A table of every week's performance was posted up for the inspection of the men, wherein the engines occupied a higher place in proportion as their consumption was lighter.

These arrangements were carried into effect in October, 1839, and immediately roused an honourable and eager spirit of competition amongst the men.

The records of that period show a marked effect. During the four weeks

preceding the 19th October, the coke deliveries amounted to 826 tons 9 cwt.; during the four weeks succeeding that day, to only 717 tons 17 cwt., the work done being almost precisely the same.

Week ending						Tons.	cwts.	qrs.
28 September, 1839.	232 trips of 30 miles			+ $34\frac{1}{2}$	days' work	207	4	2
5 October, ,,	234	do.	do.	+ $34\frac{1}{4}$	do.	203	11	1
12 do. ,,	233	do.	do.	+ $35\frac{1}{4}$	do.	211	2	1
19 do. ,,	236	do.	do.	+ $30\frac{3}{4}$	do.	204	11	0
	935	do.	do.	+ $134\frac{3}{4}$	do.	826	9	0
26 October, 1839.	233 trips of 30 miles			+ 35	days' work	181	8	1
2 Nov. ,,	233	do.	do.	+ $34\frac{1}{4}$	do.	182	3	1
9 do. ,,	230	do.	do.	+ $34\frac{1}{4}$	do.	174	14	1
16 do. ,,	240	do.	do.	+ $35\frac{1}{2}$	do.	179	11	2
	936	do.	do.	+ 139	do.	717	17	1

By further practice, and by attending closely to those little defects of which the existence was sure to be indicated by an inspection of the tables, and before any extensive improvements were made in the valves, the quantity was still further reduced, and in February of the following year did not exceed 670 tons.

THE WORKING DUTY OF STEAM.

The heat necessary to convert a given weight of water of a given temperature into steam has been ascertained to be a constant quantity, independent of the particular pressure and temperature of the steam generated, so that in respect of the duty of fuel it is a matter of indifference whether evaporation is carried on under a high or a low pressure.

A portion of the heat applied to the water is expended in elevating its temperature up to the point at which its conversion into steam of the assigned pressure commences, and the remaining portion is devoted to the conversion of the liquid into vapour, and is essential to its constitution as such.

This heat of conversion (latent heat) diminishes as the pressure and corresponding temperature of the steam increase.

For instance:

	lbs. of water.
1 lb. of water heated from 32° to 212° F. requires as much heat as would elevate through 1° F.	180
1 lb. of water at 212° F. converted into steam at 212° (=14·7 lbs. per square inch) requires as much heat for its conversion as would elevate through 1° F. . . .	972
Total	1152

Again:

	lbs. of water.
1 lb. of water heated from 32° to 329° F. requires as much heat as would elevate through 1° F.	297
1 lb. of water at 329° F. converted into steam at 329° (=100 lbs. per square inch) requires as much heat for its conversion as would elevate through 1° F. . . .	855
Total	1152

The number 1152 is, then, a constant which may be taken to express the units of heat contained in 1 lb. of steam, reckoning from 32° F., the freezing point of water, up to the temperature at which the conversion into steam takes place.

The *mechanical equivalent*, or maximum theoretical duty of this amount of heat, as contained *in* 1 lb. *of steam*, is

682 lbs. × 1152 units of heat = 785664 lbs. *raised* 1 *foot high;*

682 lbs. through 1 foot being, as before shown, the mechanical equivalent of the unit of heat.

The amount of duty realized in the production and use of 1 lb. of steam falls, however, far short of this theoretical maximum.

In the earliest stages of the process, those which precede the moment when the water finally assumes the gaseous form, the forces to be encountered before the cohesion of the molecules of the liquid can be overcome absorb and neutralize a large proportion of the effect of the imparted heat.

In fact, the 'heat of conversion' is partly occupied in producing the change of state from liquid to gas, an effect which is unattended by any sensible manifestation of power, and for the remainder consists in producing a pressure or force equal to the tension of the steam on a given area of surface moving through a space which depends on the relative volumes of the water and the steam.

Thus it is obvious that in the most perfect steam engine, acting as it does on the principle of alternate vaporization and condensation, a very considerable amount of the mechanical equivalent of heat is for all practical purposes annihilated; and this reflection may lead to the question whether there may not be discovered some means of reclaiming the lost heat of conversion, and thereby greatly economizing fuel, by the employment of water purely in its gaseous form, subjecting it to such alternations of temperature, *short* of reducing it to the liquid state, as may render it the means of transforming all the heat it receives into a manifested and available equivalent of force.

Owing to the circumstance of the heat of conversion becoming relatively less and less as the pressure increases, the loss or absorption of force is less, the higher the pressure at which the steam is produced.

Making the allowance for this loss, the theoretical work producible from 1 lb. of steam is in each of the cases here cited as follows:

	lbs. avoird. raised 1 ft. high by 1 lb. of steam. Theoretical duty.
1st. Low-pressure engine, working inexpansively, and condensing its steam at 112° F. (=1·3 lb. per square inch); the steam formed at 228° F. (= 20 lbs. per square inch)	53,150
2nd. High-pressure engine, working expansively; steam formed and admitted into cylinder at 284° F. (=$51\frac{1}{2}$ lbs. per square inch, or 3 atmospheres), expanding to 104° F. and condensed at 104° F. (= 1 lb. per square inch)	214,734

In the first case can only $\frac{1}{14}$th part of the absolute maximum of theoretical duty of the heat imparted to the steam be obtained; in the latter case, about $\frac{2}{7}$ths.

Of this reduced theoretical duty let us see how much has been actually obtained in practice.

1*st case.*—Mr. Josiah Parkes, in his Paper on Steam Engines, records the duty of two condensing inexpansive low-pressure steam engines, viz. an engine at Warwick, with 25-inch cylinder and 5-feet 6-inch stroke, and the engine of the Albion Mills, London, with 34-inch cylinder and 8-feet stroke.

The first engine raised	28,285 lbs. 1 foot high.
The second engine raised	28,489 lbs. ,,
Mean	28,387 lbs. raised 1 foot high by 1 lb. of steam.

This duty is only 53 per cent., or little more than one-half the assigned theoretical duty.

2*nd case.*—The Fowey Consols engine, with 80-inch cylinder, 10-feet 4-inch stroke, cutting off at $\frac{1}{4}$ stroke, working at a pressure of 40 lbs. per square inch above the atmosphere, has raised

126,359 lbs. 1 foot high by 1 lb. of steam.[11]

This duty amounts to at least 58 per cent. of the assigned theoretical duty. (In the case supposed, the steam would be cut off rather earlier.)

The loss of duty in respect of the steam generated in the boiler may be referred to four general heads, viz.

I. Loss as arising from steam which escapes, either without passing through the cylinders, or if passed through the cylinder, without exerting pressure upon the piston.

II. Loss as arising from resistances against the piston, produced by imperfect action of the valves.

III. An *apparent* loss incidental to the non-condensing engine, as arising from the resistance to the piston afforded by the pressure of the atmosphere.

IV. Loss as arising from imperfect condensation.

[11] The average duty of all the Cornish engines scarcely exceeds one-half this.

1. *Loss from Escapes of Steam.*

Owing to defects of mechanical construction, or to the gradual wear and abrasion of surfaces intended to work upon each other steam-tight, a waste of steam often takes place. This can only be remedied by repairs; but there is another fertile source of waste, which is in great measure under the immediate control of the engine driver,—the loss of steam blown off through the safety-valves when the engine is either standing or working. To give an idea of the loss that may be sustained in this way, the following experiments, made on the Liverpool and Manchester Railway in August, 1839, may be cited.

Four engines in good working order, viz. the 'Rapid' and 'Leopard' passenger engines, and the 'Lion' and 'Mammoth' luggage engines, were selected; and during a day's work of each, as engaged in the ordinary traffic of the line, all particulars of their service were noted down: the time in motion,—the time at rest under steam,—the times of lighting and extinguishing the fires,—the coke delivered throughout the day,—the waste coke thrown aside as useless,—the ashes taken out at night.

The results are condensed into the following Table, the consumption of fuel being reduced to a mileage rate.

Four trips, 30 miles each, made by each of the following Engines.	Average loads.	HOURS OF WORK.			CONSUMPTION OF COKE.								Consumption per hour when at rest.
		In motion.	At rest.	Total.	Whilst in motion.		During the day, actually burnt or lost.		During the day, waste excepted.		During the whole day's work, waste included.		
					per trip.	per mile.	per trip.	per mile.	per trip.	per mile.	per trip.	per mile.	
		h. m.	h. m.	h. m.	c. q. lb.	lbs.	c. q. lb.	lbs.	c. q. lb.	lbs.	c. q. lb.	lbs.	lbs.
Rapid	10 carriages	6 21	11 19	17 40	9 0 3	33·7	10 1 20	38·9	10 2 24	40·0	10 3 0	40·1	67
Leopard	8 ditto	5 56	10 52	16 48	8 2 25	32·6	10 2 17	39·8	10 3 19	40·8	11 1 0	42·0	97
Lion	15 waggons	7 22	9 13	16 35	10 2 3	39·4	11 3 10	44·2	12 0 25	45·6	12 1 8	46·0	99
Mammoth ..	17 ditto	7 0	12 55	19 55	12 0 25	45·6	13 2 2	50·5	14 0 10	52·9	14 0 14	52·7	63

By this account it is seen, that under circumstances in which more than ordinary care was taken in the working of the engines, the waste of coke going on whilst the engines were at rest averaged about 80 lbs. per hour; or, calculated upon the mileage, about 7 lbs. per mile, being an increase of more than one-sixth on the net consumption whilst in motion.

The trial led to a few simple regulations, which resulted in effecting the saving of nearly the entire quantity of fuel consumed whilst the engines were standing. These were as follow: as the engine approached the end of its journey, the fire in the fire-box and the water in the boiler were allowed to run low. Before

reaching the station, the feed-pumps were put on and the boiler filled up with water from the tender, the water being of course comparatively cold: after the fire-man had cleaned his bars and picked the tubes, the fire-place was filled up with cold coke: a damper was placed over the mouth of the chimney, and the engine remained in this condition until the time of starting on its next journey. By this time the coke had become ignited throughout; the water had been raised to the boiling point, and if any steam had been generated, it was turned into the tender tank, to warm the feed water. Thus the heat produced during the interval of rest was turned to full account, and made to tell directly upon the work of the succeeding journey.

II. *Loss from Resistances against the Piston, produced by imperfect Action of the Valves.*

This is a branch of the subject deserving especial consideration. Its importance, as referring to the economical working of steam engines, may be profitably illustrated by a brief historical account of the consecutive alterations and improvements in the valve arrangements and mechanism of the locomotive engines of the Liverpool and Manchester Railway, and of the results produced in the saving of fuel.

It may be premised that the same principles have their application not only to the engines of other railways, making due allowances for difference in the gradients and difference in the loads and dimensions of engines, and difference of speed, but also to fixed engines in general. In fact, they have been applied to the fixed engines of the Liverpool and Manchester with parallel advantageous results.

The history of the Liverpool and Manchester locomotive engines may, for the sake of convenient classification, be divided into two periods: the first a period of increasing, the second a period of decreasing consumption, as respects the article of fuel. Brief allusion may be made to the events of both periods, and a reference to the causes which retarded, as well as to those which accelerated, improvement.

During the first few years after the opening of the railway, the class of improvements comprising the gradual enlargement of dimensions as necessary for maintaining higher rates of speed, and the transport of heavy loads,—the better disposition and proportionment of the component parts, and selection of suitable materials capable of resisting heavy strains, and various other causes of derangement and decay, demanded, in consequence of their direct influence upon the traffic of the Company, unremitting attention. The necessity of securing regularity in the transport of trains, whether of passengers or goods, was pressing and paramount, and afforded sufficient materials for thought and experiment. It is therefore a source of less surprise than regret that little progress should have been made in diminishing the consumption of fuel. Trials of the consumption of different

engines of similar size and power, were made from time to time; and these agreeing pretty closely together, served to lull suspicion of unnecessary waste of fuel. As the engines increased in dimensions, the consumption of fuel increased also, which was considered a natural and inevitable consequence of the exertion of increased power.

The adoption, in 1836, for the passenger traffic, of what were termed short-stroked engines, was attended with the establishment of a quicker rate of travelling than had before been known on the line, but unfortunately also with an extravagant increase in consumption of coke. This was erroneously referred to the mechanical disadvantage of the short stroke, an explanation which for a time was deemed satisfactory. Attention was directed to schemes of smoke-burning, by which the use of coal, as a much cheaper fuel than coke, might be rendered possible. In 1836, the 'Liver' was fitted up for burning coal, but proved a failure; and subsequently one or two engines were tried with about equal success. Hitherto all the engines had been furnished with the slide-valve ordinarily used in high-pressure engines, the mode of operation of which is well known to every practical mechanic. It will be remembered, that the operations of admitting the fresh steam and releasing the waste steam are alternately performed by the same valve and by the same motion. The valve being made to slide backwards and forwards upon the face of the ports, opens and closes the several passages in their turn. The two extreme ones, termed steam-ports, communicate with either end of the cylinder. The middle one is termed the exhausting port, and its corresponding passage terminates in a pipe open to the atmosphere and carried into the chimney. Steam is admitted freely into the steam chest from the boiler. The valve is made of sufficient length to cover, when placed in the centre of the stroke, *all* the ports. In this position no steam can enter the cylinder; but as the valve moves on, one of the ports opens, and the arrangement of the valve gearing is such, that when the piston is ready to begin its stroke, the steam-port *begins* to open. During the forward progress of the piston, the valve not only travels to the end of its stroke, but returns to the point from whence it set out. Its continued motion in the same direction finally closes the valve, and prevents any further admission of steam. The steam has now done its work, and must be removed. In the middle of the valve a hollow chamber is formed, of sufficient length to span between the ports. As soon as the edge of this chamber passes the edge of the steam-port, the pent-up steam finds vent, and rushing through the chamber into the exhausting passage, escapes into the chimney.

This is the valve (see Plate II. fig. 1) used on the Liverpool and Manchester Railway until the year 1838, and used in the engines of other lines of railway at that time. Referring to Plate I. figs. 1, 2, 3, 4, 5, it will be observed that

the exhausting port opens when the steam-port closes, and both events happen as nearly as may be at the end of the stroke. The perfection of a slide-valve consists, other things being supposed equal, in the degree of nicety with which its motion is *timed*, relatively to the motion of the piston. The functions of the piston are absolutely dependent upon the proper *timing* of the admission and release of the steam. A most slight and apparently trifling error in the adjustment produces a most serious effect upon the consumption of fuel.

If from any cause the valve should open to admit steam for a fresh stroke before the preceding stroke is finished, it opens too soon, and an unnecessary resistance to the piston is produced.

If, on the other hand, the valve should delay its opening until the piston has begun to return, it opens too late, because then the steam has uselessly to fill the space left vacant. Hence a waste of steam and loss of power. As far, then, as the *admission* of steam is concerned, it is a necessary condition that the steam-ports should open neither before nor after, but at the precise moment when the stroke commences. Some engineers indeed have recommended giving the valve '*lead*,' as it is termed, that is to say, setting it so as to open a little before the completion of the foregoing stroke; but it seems very questionable whether the slightest advantage is gained by doing so to a greater extent than is necessary to compensate for any slackness in the parts of the valve gearing, or for their expansion when hot; and about $\frac{1}{16}$th of an inch may be considered sufficient for this purpose in a well-constructed engine.

The valve shown in Plate I. figs. 1, 2, 3, 4, 5, or Plate II. fig. 1, satisfies the conditions required in the *admission* of steam. It opens exactly at the right time. The steam begins to enter as the piston begins to move, and follows it steadily and effectively throughout its course. Whatever time the piston takes for its journey, the steam is allowed as much time to follow it. At first the opening is small, but then the motion of the piston is comparatively slow, and therefore the supply keeps pace with the demand.

As respects the *release* of the steam when the stroke has been completed, the performance of this valve is altogether unsatisfactory, and here lurks the cause of the difference in the performances of the old and the later engines of the Company.

But it might be said, the release *does* appear to take place at the right time, because it occurs just when the piston has finished the stroke, and if it were to occur before, a loss of power would ensue. This is a plausible view of the case, and one which undoubtedly delayed for years the saving of fuel which has since been effected.

Sufficient attention was not bestowed upon the processes going on in the

interior of the cylinder, or upon the facts which might have indicated them. Alternately to fill and empty the cylinder of its contents, are operations requiring *time*. The time allowed for the first operation, that of filling the cylinder with steam, necessarily corresponds with the duration of the stroke, whatever its duration may be. But this cannot be the case as regards the second operation, the emptying of the cylinder. This ought to be performed in an instant, in the minutest fraction of the duration of the stroke, otherwise the steam continues pent up when it ought to be liberated,—when it ought to assume its minimum pressure, the pressure of the atmosphere,—and exerts an injurious counter-pressure against the piston, tending to increase the resistance to be overcome.

To effect the free and rapid discharge, it is necessary, not merely to open the communication to the exhausting pipe, but to open a *wide* passage, and to have this *done* by the time the piston recommences its motion. The valve alluded to cannot accomplish this. Its motion is gradual, not instantaneous. The passage only begins to open when the piston is on the turn, and is not wide open until the piston has travelled through one-tenth of its entire stroke. The steam in the cylinder is consequently restrained from escaping, being wire-drawn in the passage out, and consequently takes *considerable time* to assume the pressure of the atmosphere.

In the mean while the new stroke has begun, and been partially completed; and so far the piston has had to contend with a resistance altogether illegitimate,—a resistance which in many cases, and especially at high speeds, has been nearly equal to all the other resistances put together.

In the year 1838, as above mentioned, the extent of the disease was first suspected, and a remedy attempted. It had before been observed that the giving of an engine '*lead*' tended to improve its speed when travelling, already at a high speed, and with a light load. The circumstance was attributed to the opening of the steam-port being wide at the time of commencing the stroke, thereby increasing the facility for the entrance of the steam in following up the piston.

Its true explanation was found to be the earlier release of the waste steam, and consequent diminution of resistance. As sometimes $\frac{3}{8}$ths of an inch or even $\frac{1}{2}$ an inch 'lead' was given in passenger engines, it was decided to try the effect of opening the exhausting passage earlier by the same amount, whilst the steam-port should still be made to open only at the turn of the stroke. An engine called the 'Lightning' was chosen for the experiment. Its original valve resembled fig. 1, Plate II.;—placing the valve on the ports, so as to allow the exhausting passage to be $\frac{3}{8}$ths of an inch open, the steam-port would at the same time be $\frac{1}{4}$ inch open. This space therefore was closed by adding to the length of the valve

at each end $\frac{1}{4}$ inch. The eccentric was of course shifted on the axle to correspond with the alteration, and the engine with the altered valve (see fig. 2, Plate II.) was again set to work in March, 1838. The amount by which the valve at each end overlaps the steam-ports, when placed exactly over them, is technically termed the '*lap.*' The lap of the 'Lightning's' valve being then $\frac{5}{8}$ths of an inch, the exhausting passage was about $\frac{3}{8}$ths of an inch open when the stroke was finished. This engine was made the subject of several experiments. With coach trains, the saving in fuel was very considerable; the consumption, whilst running, being only about 25 lbs. per mile with loads of five to eight coaches, and the speed was considerably improved.

It here becomes necessary to refer to the consumption of the Liverpool and Manchester engines before and at the time we speak of, in order to form a just conception of the position arrived at.

The amended performance of the 'Lightning' was little better than the best performances at the end of the year 1830. The 'North Star,' 'Phœnix,' 'Arrow' and 'Meteor,' engines of that period, when in first-rate condition, and expressly put upon trial, consumed about 25 lbs. per mile; but this was with loads of only four carriages, and at a very inferior speed.

Again, in June, 1832, the 'Victory' and 'Planet' were burning about 30 lbs. per mile, with coach trains. In 1833, the 'Sun' and 'Etna' used about 28 lbs. per mile. This is their consumption when actually running, *i. e.* their net consumption.

The experiments of M. De Pambour, in 1834, were carefully conducted, and may be fully relied upon. In his 'Treatise on Locomotive Engines,' (2nd edition, page 312, 1840,) he gives a table, by which it appears that the best performances of the best engines, as the 'Jupiter,' was 26·3 lbs. coke per mile, with 8 coaches, at 24·58 miles per hour; and the best performance of luggage engines, 38 lbs., with 25 waggons (= 120 tons), at 17 miles per hour. This was their net consumption. The distinction between the total amount of fuel consumed by any engine, and the fuel it consumes when actually running, must be carefully borne in mind. It will be marked by the terms *net* and gross consumption. Coke must be burnt in raising the steam, and afterwards in keeping it up during the intervals of rest, which therefore enters into the gross, but not into the net consumption.

In 1836 and 1837, larger engines were gradually introduced, to replace the smaller class, which had become insufficient for maintaining the higher rate of speed then demanded; and their increased consumption of fuel was commensurate with their increase of size.

For an idea of the general effect attendant upon their introduction, the following table, showing the coke consumed in several consecutive years, may be consulted:

11,561 trips	in 1835	=	7907 tons coke gross.	
12,063 ,,	1836	=	9876 ,,	,,
12,953 ,,	1837	=	10816 ,,	,,

Thus, during three years when the change went on, although the work done increased only in the proportion of 100 to 112, the consumption of fuel increased in the proportion of 100 to 136, without any material difference in the magnitude of the loads.

In 1838 and 1839, the average consumption attained its maximum, being about 49 lbs. per mile gross with passenger trains averaging seven coaches, and 54 lbs. per mile with luggage trains averaging sixteen waggons.

Forty pounds *net* consumption, with coach trains, was moderate for such an engine as the 'Lightning;' and the performance of the 'Lightning,' when altered, being under 30 lbs. net, was naturally considered favourable. This result was evidently obtained from the earlier exhaustion of the steam.

Whereas previously the opening of the exhaustion passage was contemporaneous with the termination of the stroke, now it took place before, and was already $\frac{3}{8}$ths of an inch open at the end of the stroke. A portion of the steam could by that time escape, and the back pressure was diminished.

The valves of two engines, called the 'Rapid' and 'Arrow,' were next altered, to have $\frac{3}{8}$ths of an inch lap; the 'Rapid' in January, the 'Arrow' in June, 1839. During the last quarter of the year 1839, the *gross* consumption of the 'Rapid' was $36\frac{1}{2}$ lbs. per mile; and that of the 'Arrow' 40 lbs. per mile; and the net consumption probably about 30 and 33 lbs.

Arrow.—*Valve with $\frac{3}{8}$ths of an inch lap.*

Week ending	Trips	Coke. cwt.	qrs.	lbs.		per trip. cwt.	qrs.	lbs.		per mile. lbs.
January 4, 1840,	12 trips of 30 miles,	130	0	0						
,, 11, ,,	12 ,, ,,	127	2	0						
	24	257	2	0	=	10	2	25	=	40·1

Valve with $\frac{3}{4}$ths of an inch lap.

Week ending	Trips	cwt.	qrs.	lbs.		cwt.	qrs.	lbs.		lbs.
February 9, 1840,	10 trips of 30 miles,	88	3	0						
March 7, ,,	8 ,, ,,	71	1	0						
,, 21, ,,	14 ,, ,,	118	3	0						
,, 28, ,,	16 ,, ,,	137	2	0						
	48 trips,	416	1	0	=	8	2	19	=	32·4
									Difference	7·7

Here was a confirmation of the principle first recognized in the case of the 'Lightning;' and it became a question how far this principle might be advantageously carried out, and whether the exhaustion might not be made to take place still earlier. This could not be accomplished without, at the same time, cutting off the steam earlier; or, in other words, by virtually shortening the stroke. The fear of impairing the power of the engine at first deterred from venturing the experiment; but at length a trial was made in the 'Arrow,' whose valve was altered to have $\frac{3}{4}$ths of an inch instead of $\frac{3}{8}$ths of an inch lap at each end. (See fig. 3, Plate II.) Since the travel of the valve remained as before, the valves did not open quite full port, but only $\frac{7}{8}$ths of an inch. In February, 1840, the alteration was effected, and an immediate reduction of nearly 8 lbs. per mile was the result. The gross consumption of this engine with coach trains was 40·1 lbs. before the alteration; it was only 32·4 lbs. after it. A saving of 20 per cent. had been effected: at the same time, no injurious effect was observed upon the power, but rather the reverse.

An invention, which was made a little before the time we now speak of, tended more completely than any thing had hitherto done to show the impossibility of fixing any ultimate determinate standard of consumption, and consequently gave a considerable impulse to the further improvement of the engines. This was the patent expansive valve gearing of Mr. John Gray, as applied to the 'Cyclops,' an engine of the same dimensions and make as the 'Lightning.'

This engine underwent a thorough repair in the summer of 1839; and in October, soon after it came out, was made the subject of an extensive series of experiments.

The alteration consisted in the adaptation of particular mechanism for working the valves, whereby the engine-man was enabled, without disturbing the regulator, to vary at pleasure the quantity of steam admitted into the cylinder within the limits of a range extending from 46 to 82 per cent. of the length of the stroke, allowing the steam to act expansively after being cut off.

The advantages proposed to be attained by the arrangement were, to accommodate the power of the engine to the load to be conveyed, and to the inclinations of the road; to establish, in fact, a property of adjustment, by the aid of which an engine, constructed for the transport of very heavy loads, might be adapted to the exigencies of an irregular and uncertain traffic, without entailing any unnecessary expenditure of fuel.

The conclusion arrived at upon completing the experiments was, that a saving of at least 12 per cent. in fuel over the best engines had been effected by the application of the new gearing, without occasioning any diminution in the speed of travelling.

Its net consumption was $22\frac{1}{2}$ ℔s. per mile; its gross consumption $28\frac{1}{2}$ ℔s. per mile, with loads of seven coaches.

This, though little better than the performance of the 'Arrow,' in March, 1840, was, it will be remembered, accomplished four or five months before, and was in fact the cause of a keener prosecution of the trials with different valves.

Whether or not the favourable results of the 'Cyclops' were actually due to using steam expansively, is a point upon which engineers may not perhaps be agreed; but the subsequent history of the locomotive engine has made it apparent that the expansive action only partially contributed to the success of the experiment.

In Mr. Gray's apparatus, the time of closing the steam-port was made to vary by altering the length of the travel of the valve, and a simultaneous adjustment of the position of the valve on the ports took place to suit the altered travel, making the valve still to open at the right time. The old valve would not have been applicable, nor have fulfilled the specified conditions; for, bearing in mind that in any case the steam-port is to open when the stroke of the piston commences, and that the old valve was scarcely longer than was just sufficient to cover both steam-ports, it is evident that an alteration merely in the *travel* of the valve would not have allowed the steam to act expansively, since the steam can only so act when *both* steam-ports are closed; that is, whilst the valve is travelling through a space equal to the length of the external lap, plus that of the internal ($= \frac{7}{8}$ inch $+ \frac{3}{8}$ inch $=$ $1\frac{1}{4}$ inch in the case of the 'Cyclops'). Therefore *lap* was given to the valve both internally and externally; *internally*, to delay the opening of the exhausting passage; externally, that *time* might intervene between the operations of exhausting the waste and admitting the fresh steam. (See fig. 4, Plate II.)

And inasmuch as the external lap exceeded the internal, by so much the arrangement resembled, and in fact partook of the principle of the valves of the 'Rapid' and 'Arrow,' the result of their difference being, that the exhausting passage was half an inch open at the end of the stroke.

To this principle, viz. the earlier exhaustion of the waste steam, and to the higher pressure of steam in the boiler, may be ascribed the improvement in the 'Cyclops.' Whatever benefit may have been derived from expansive working was, to a considerable extent, neutralized by the compression of the waste steam left in the cylinder after the closing of the exhaustion passage, an evil which increased in proportion as the steam was cut off earlier.

The next important improvement in the valves is due to Mr. Dewrance, and was suggested by him early in the year 1840. His principle was, that the exhausting passage, instead of being only partially open at the moment of completing the stroke, as was more or less the case with the engines before named,

should be nearly wide open, which was to be accomplished by making the 'lap' of the valve equal to the width of the steam-port. Moreover, that the travel of the valve should be made proportionate to the increased lap, so as to allow the same area or the same amount of opening of the steam-port for the admission of steam. This latter condition was not fully obtained in the instances of the 'Lightning,' 'Arrow,' and 'Rapid.' It would at least have involved the sacrifice either of the eccentrics or other parts of the valve gearing, in order to obtain the additional travel of the valve, and perhaps might have been altogether impossible from want of room in the steam chest itself. Therefore in those engines, after being altered, the valves did not open so wide as before.

A favourable opportunity now occurred for carrying out these ideas, both as regarded increased lap and increased travel, from the circumstance of two engines requiring extensive repairs, which would allow time for the needful alterations.

One inch lap was given to the 'Rapid's valve, which was now made to travel $4\frac{1}{4}$ inches. (See fig. 5, Plate II.) The result of this arrangement was, that the exhausting passage was one inch open at the end of the stroke, and that supposing the stroke of the piston divided into 100 equal parts, the steam was cut off at 79; it expanded from 79 to 95; at 95 it began to be released, and was escaping into the atmosphere from 95 to 100. The operation of this valve is shown in figs. 6, 7, 8, 9, 10, Plate I.

The 'Rapid's *gross* average consumption of coke, when running sixty-four trips of thirty miles each with coach trains, *before* the alteration, was 36·3 ℔s. per mile; and 28·6 ℔s. per mile immediately *after* the alteration.

Thus we have a measure of the effect produced—a saving of one-fourth of the fuel.

It had become a question whether the Company should not proceed to adapt the expansive gearing to more of their engines; but an engine having now been made to rival the 'Cyclops,' without in any degree increasing the complexity of the gearing, it was considered more desirable to delay proceedings until the simpler method was fully tested by numerous experiments.

To accomplish this in the then existing engines was found to be no easy task; for on examination it was discovered that, in many cases, there was no room in the steam chest for valves of greater lap; in others, that it was impossible to increase the length of travel. Therefore it was necessary to prepare, in the first instance, for the sacrifice of at least the cylinders, steam chests, working gear, and inside framing of several engines then needing repair, and eventually, as resources would permit, for replacing the Company's entire stock with new engines, all built according to one model, combining the latest improvements experience had shown

worthy of introduction, trusting that the saving in fuel, and in the general expenses of repairs, would speedily repay the Company for the immediate sacrifice. These views fortunately proved to be well founded. The loss was soon recovered; for the saving in the cost of fuel and repairs considerably exceeded the outlay, and although during the years 1840, 1841, 1842, the Company turned out from their workshops twenty-four new engines, (the cost of the whole being debited to current disbursements, under the head of 'Locomotive Power,') and broke up as many old ones, yet at the same time the total expenses of the locomotive department underwent a gradual reduction from £51,580 per annum, the charge in 1839, to £25,732, the charge in 1842.

Some engines, such as the 'Vesta,' 'Swiftsure,' 'Phœnix,' 'Etna,' 'Rokeby,' 'Meteor,' and 'Sun,' were altered at a trifling expense, so as to approximate towards the improved principle, and thus tended to keep down the consumption of coke whilst more perfect engines were in course of formation.

The 'York' was several months under repair, and did not come into action until 1841.

Finally, all the engines belonging to the Company were furnished with the improved valve, (see fig. 5, Plate II.,) answering to the 'Rapid's, the lap being 1 inch, the travel 4 inches, the ports $1\frac{1}{8}$ inch wide. In casting new cylinders, great care was of course taken to enlarge the area of the passages of exhaustion, most of the older engines having been too much contracted at this part. Attention to this point exercised a further beneficial effect in saving fuel.

Every step towards increasing the 'lap' was thus found to conduce to the good working of the engine. The waste steam was no longer choked up in the cylinder; its prejudicial resistance was removed, and, in consequence, a much less quantity of steam and fuel sufficed to do the same useful work. As a further consequence, the area of the blast-pipe could be enlarged without risk of a deficiency of steam, the coke was no longer chafed by the violence of the draft, and the fire-bars could be placed closer together, to diminish the loss of fuel dropping between them.

Having considered the effects of the old and the new valve with reference to the motion of the piston, it may be interesting also to compare the times allowed in either case for the performance of the function of releasing the steam, as by so doing we may gain a clearer conception of the difference subsisting between them.

Supposing the velocity of the engine to be uniform, the angular velocity of the crank is uniform also. Half a revolution of the crank, equal to 180°, corresponds with one stroke of the piston. Let us assume the stroke, or, which is the same thing, a half-revolution of the crank, to be accomplished in a unit of time.

We shall find, as a matter of fact, from the known relative motion of the crank and piston-rod, that the angular motion of the crank from the initial or dead point has been as follows, up to the moment when the exhaustion passage begins to open, the valve being set without lead.

	Angular motion of crank from dead point.	Remaining to be passed over.
Valve with 0 inch lap	0° to 180°	0°
" $\frac{3}{8}$ "	0° to 165°	15°
" $\frac{3}{4}$ "	0° to 158°	22°
" 1 "	0° to 153°	27°

Therefore the times are as

$\frac{0}{180}$	corresponding with	old valve,
$\frac{15}{180}$	"	Lightning's,
$\frac{22}{180}$	"	Arrow's,
$\frac{27}{180}$	"	new valve,

or as the numbers 0, 15, 22, 27, which represent the *relative* times allowed for performing the release of the steam by the four different valves.

There is of course a limit to the application of this principle. The time gained for exhaustion is time lost, as regards the application of the power of the steam: in other words, the sooner we begin to exhaust, the sooner we must cut off the steam; the more we must reduce the length of the effective stroke.

Finally, a point is arrived at where the loss of power from earlier cutting off is equalled by the illegitimate resistance of back pressure removed, and up to this point we cannot do wrong in going; for then, without impairing the useful power of the engine, we are saving all the fuel necessary to overcome what would otherwise be back pressure. In practice it is found, that under an equal pressure of steam the one-inch lap does not impair, but rather improves the tractive power of an engine when travelling with a maximum load, and much more, therefore, with any load short of the maximum.

III. *Loss from Resistance of Atmosphere against the Piston.*

This is a loss incidental to all forms of the non-condensing engine; but its amount varies relatively to the useful effect produced, according to circumstances over which the engineer has in some measure a control, and it rests with him so to proportion the dimensions of the cylinder and the speed of the piston to the resistance required to be overcome, as to render the loss the least possible.

After the exhausting passage has been fully opened, and before the piston begins its stroke anew, the cylinder, being now open to the atmosphere, is filled with steam equal, at least, to the pressure of the atmosphere; which pressure therefore

has now to be driven before the piston. The quantity of steam expended in neutralizing the pressure of the atmosphere for one stroke of the piston is a volume equal to the contents of the cylinder at a density corresponding with the pressure of 14·7 lbs. per square inch; and the volume of water necessary for producing it is equal to $\frac{1}{1700}$th part of the volume of such steam.

The evaporating power of any given boiler being limited, it is easy to see that the area of the piston and velocity of its motion must bear a direct reference to the rate of evaporation; for otherwise a result ranging between the two following extreme cases may occur: either the volume measured out by the pistons in a given time may be smaller than the boiler is competent to fill with steam of the requisite density,—in which case the pressure in the boiler will increase, and the excess of steam will escape through the safety-valves,—or the volume measured out by the pistons in a given time may be so great as to reduce the pressure until it scarcely exceeds that of the atmosphere; in which case the force of the steam generated is nearly wholly absorbed in overcoming the atmospheric pressure on the pistons.

In fixed engines, working as they generally do under nearly constant loads at nearly uniform velocities, the relation between useful effect obtained and the work expended in neutralizing the pressure of the atmosphere seldom varies, at least not sufficiently so to attract attention; but in locomotive engines the tendencies towards the above-mentioned extremes are more strongly marked, in consequence of the great variation in load and speed to which they are constantly subject.

In any non-condensing engine we may conceive the duty of the water evaporated, and therefore of the fuel which produces the evaporation, taken irrespective of waste, as divided into two parts; one of which is constant for equal spaces traversed by the piston or by the engine, the other variable and dependent upon the load.

If we take as an example the Liverpool and Manchester passenger engine of 1840 to 1845, with 12-inch cylinders, 18-inch stroke, and 5-ft. wheels, and take one mile as the unit of distance traversed, we find the volume of steam expelled to be

336 revolutions × 4 cylinders full × 1·162 cube feet = 1562 cube feet per mile.

With the ordinary loads of say seven or eight coaches, about 15 lbs. of coke are consumed and (15 × $7\frac{1}{2}$) 112 lbs. of water. 112 lbs. of water converted into 1562 cube feet of steam has its volume increased 869 times, which answers to a pressure of 30·5 lbs. per square inch as the average total force applied to the piston. Of this total force 14·7 lbs. are expended in neutralizing atmospheric pressure, and the remainder only to overcoming the external resistances of the engine and train. Here loss from pressure of the atmosphere is as great as the useful effect.

Apply the same engine to the conveyance of a heavier load, say a luggage train of 100 tons: the consumption of water now becomes 150 lbs. per mile instead of 112 lbs. as before, with the lighter load; but the steam used in overcoming atmospheric pressure is the same.

The relation between the total work of the steam and the useful effect has therefore changed from the ratio of

100 : 50 in the 1st case, to that of
100 : 62 in the 2nd case.

Suppose the area of the cylinders of the same engine reduced to *half* their original size, all other parts remaining the same, but the working pressure increased to make up for the reduction of area; then the loads being as before, the relation of total work to useful work will be as the ratios

100 : 74 in the 1st case,
100 : 80 in the 2nd case,

which is equivalent to a gain of about 20 per cent.; or if we suppose the area of the cylinders to be *doubled*, the ratios would become as

100 : 0 in the 1st case,

indicating that no useful effect is obtained, and that the whole of the steam is applied to the neutralizing atmospheric pressure, and as

100 : 24 in the 2nd case.

The practical considerations which limit and determine the proper proportions of the cylinder and wheels are chiefly these:

1st, The most convenient maximum working pressure, having due regard to safety.

2nd, The maximum resistance to be encountered by the engine, say at starting or at any stage of its journey.

3rd, The surplus power in excess of maximum resistance, as necessary for obtaining a sufficiently rapid acceleration of speed after starting a train.

The evaporating power of the boiler must necessarily be a function of the speed to be maintained under the conditions of the average resistance.

In engines of different proportions, the 'constant' consumption of water and fuel will vary directly as the square of the diameter of the cylinder, directly as the length of stroke, and inversely as the diameter of the driving wheels: in other words, it will be proportional to the volumes of steam measured off by the cylinders in traversing the same unit of distance.

Computing the 'constant' consumption for three sizes of engine, viz.

No. 1. The Liverpool and Manchester passenger engine, above referred to, ...	12″ cylinder, 18″ stroke, 5-ft. wheels,
No. 2. The larger and standard size now made for trains running between Liverpool, Birmingham, and Manchester,	15″ cylinder, 20″ stroke, 6-ft. wheels,
No. 3. The Great Western Railway passenger engine, 'Great Britain,'	18″ cylinder, 24″ stroke, 8-ft. wheels,

we have

No. 1	consuming	57·26 ℔s.	of water per mile,	and	7·63 ℔s.	of coke per mile,
No. 2	„	82·83	„	„	11·04	„
No. 3	„	107·36	„	„	14·31	„

(allowing $7\frac{1}{2}$ ℔s.[12] water to 1 ℔. coke,) before any effective work can be obtained from the steam.

It would be impossible to prescribe any general solution of the problem of the proportions of the cylinders and driving wheels of engines, seeing that very various and complicated considerations are involved, referring to conditions imposed by the nature and amount of the traffic; as, for example, the extent to which it must be subdivided into individual trains,—the speed at which it has to be conveyed,—the gradients of the railway. Nevertheless it may be borne in mind that the greater the pressure at which the steam is made to act in the cylinders, and the smaller the volume of steam emitted on the journey, the greater will be the saving in fuel.

Generally speaking, the pressure of steam in the cylinder is much below the pressure in the boiler when the engine is travelling at a high speed.

On starting a train, or for enabling it to surmount an occasional steep inclination, it is most desirable to have large cylinders, to gain the requisite amount of power; but when the speed has been attained, or the incline surmounted, the force is reduced, the steam becomes attenuated in the cylinders, and the large cylinders are the direct occasion of waste of fuel, and in fact prevent the attainment of as high a velocity as would result under the same circumstances, were the cylinders smaller.

The contrivance of some easy method of varying the power of an engine whilst in motion is still a desideratum.

In one way indeed this is already in many instances done by cutting off the steam at different points of the stroke, and working expansively; but considering the comparatively low average pressure which the steam assumes in the cylinder at high speeds, and that it cannot be allowed to expand *below* the pressure of the atmosphere,—also that the last atmosphere remaining in the cylinder has not taken any part in the 'effective' duty of the engine, but is, so to speak, thrown away, whether the engine is worked expansively or not,—it seems very doubtful in theory,

[12] *i.e.* $7\frac{1}{2}$ ℔s. of water evaporated from say 50° F.

and the results of practice would seem to confirm this view, whether any real advantage is gained by the so-called expansive working.

Some simple and inexpensive means of effecting a condensation of the *last* remaining atmosphere of steam, reserving the excess above one atmosphere for producing the blast, combined with the means of working expansively, would effect all that is desired, and at the same time permit a reduction in the size and weight of the boiler and engine.

IV. *Loss as arising from imperfect Condensation, and from Heat carried off by, and not recovered from, the condensing Water.*

In the condensing engine, the heat abstracted from the steam is imparted to the injection water, and to the water surrounding the condenser, and the temperature of the condensing water is elevated. The resistance to the piston, per unit of surface, after condensation has taken place, is equal to the tension of saturated steam, as answering to the final temperature of the injection water.

At a temperature	60° F.	the force of vapour is		0·26 ℔.	per square inch.
,,	80° F.	,,	,,	0·50 ℔.	,,
,,	100° F.	,,	,,	0·93 ℔.	,,
,,	120° F.	,,	,,	1·65 ℔.	,,
,,	140° F.	,,	,,	2·88 ℔.	,,

In condensing a given weight of steam, the greater the quantity and the lower the temperature of the injection water used, the less will be the tension of vapour, and consequent counter-pressure.

In practice, a final temperature of 120° F. in the injection water = 1·65 ℔. pressure per square inch, may be considered an average result. Suppose the initial temperature to be 52°, the quantity of injection water admitted must be at least 16 times the weight of steam condensed; for

	Units of heat.
In 1 ℔. of steam there exists, as measured above the freezing point (32° F.), .	1152
From this deduct 120°— 32	88
The difference is the number of units of heat abstracted from the steam to reduce it to water and vapour at the final temperature of 120° F. = ...	1064

To every pound of the cold injection water (120° — 52° =) 68 units of heat are added; consequently 1064 ÷ 68 = 15·6 ℔s., the weight of water required to condense 1 ℔. of steam, about $\frac{1}{16}$th part of the heat imparted to the injection water, when pumped out of the condenser, is restored to the service of the engine: the remaining $\frac{15}{16}$ths go to waste.

It has been ingeniously proposed in a recent patent, that of Mr. Siemens, to obviate much of this loss by employing a peculiar form of condenser and

arrangement of the valves, by which the steam issuing from the cylinder shall be presented in successive portions to a range of compartments in the condenser, in such order that the hottest steam comes in contact with the hottest condensing water; the next portion in contact with cooler water, and so on, until the last expansion is condensed with water of the temperature at which it can be obtained; a series of operations which, although strictly consecutive, may be conceived as being practically simultaneous. The injection water entering the condenser at a temperature of 52° would issue from it at the boiling point, and be pumped from thence into the boiler at a temperature 92° higher than it attains in the usual manner, effecting a corresponding saving of fuel, besides accomplishing a more perfect condensation. With the aid of such an apparatus, it has been also suggested to render the present non-condensing engine partially condensing by the use of a very limited supply of condensing water, allowing part of the steam to escape in the usual way through the eduction or blast-pipe, and to condense only the remaining volume of steam as at, or below, the atmospheric pressure.

The injection water entering at 52° and issuing at 212°, would carry off from the steam 160 units of heat. Those portions of the steam which condense at 52°, or at other temperatures *below* 212°, act the part of *condensing water* in the successive compartments of the condenser, until finally the condensed steam issues from the last compartment at 212°. Consequently the condensed steam merely gives up its latent heat, 972 units (1152° — 180°), and the proportion of condensing water to steam would be as 972 : 160, or as about 6 : 1.

Reverting, for the sake of illustrating the general case of a non-condensing engine, to the case of the locomotive with 12-inch cylinder, 18-inch stroke, and 5-ft. wheels, we have seen that the weight of steam passing through the cylinders per mile for neutralizing atmospheric pressure was 57·26 lbs. To condense this ($57·26 \times 6 = 344$ lbs. or) 35 gallons of water per mile would be required. Supposing the engine to be working with a load equivalent to a *total* pressure of four atmospheres on the pistons, the water evaporated to supply steam of that pressure would be, exclusive of waste, (1562 cubic feet of steam divided by 474, the relative volume of steam at that pressure to its producing water, = 3·3 cube feet, or) about 20 gallons per mile. The boiler would be supplied with 20 gallons per mile (plus whatever might supply waste) from the water at boiling point derived from the condenser, and the remaining 15 gallons (or less) of heated water would go to waste. If such an additional supply of water could be maintained without inconvenience, the advantages resulting would be —

1st, An increase of effective power in the engine in the ratio of 3 atmospheres to 4 atmospheres, for the *same* quantity of water evaporated or fuel used, irrespective of any benefit from expansive working.

2ndly, The opportunity of working the steam expansively to a greater extent than has hitherto been practicable.

3rdly, That the boiler is fed with hot water.

Having considered in some detail the circumstances which influence the working duty of fuel in respect of the production of steam, and the working duty of steam in respect of the production of force, it may be well to present a general summary of the results already noticed, so as to exhibit at one view the aggregate influence of all the causes which combined to diminish the consumption of fuel in the Liverpool and Manchester engines.

In the first Table annexed, the performances of the various engines mentioned are shown.

In the second Table, the progressive reduction in consumption of fuel is noted, with a brief explanation of the causes.

TABLE I.

Date.	Engines.	Observations.	Gross Consumption.	Net Consumption.	
			lbs. ℔ mile.	lbs. ℔ mile.	
1830.	North Star..	Loads of 4 carriages ..	......	25·0	
	Phœnix				
	Arrow......				
	Meteor				
1832.	Victory	Ditto	......	30·0	
	Planet......				
1833.	Sun........	Ditto	......	28·0	
	Etna				
1834.	Jupiter	Load of 8 carriages.			
1838.		Average of all coaching engines	49·0	40·0	Loads of 7 carriages.
March	Lightning ..	$\frac{3}{8}$-inch lap to valve....	......	25·0	
1839. Nov.	Rapid	$\frac{3}{8}$-inch ditto	36·3	30·0	
Nov.	Arrow......	$\frac{3}{8}$-inch ditto	40·1	33·0	
Nov.	Cyclops	Gray's patent gearing .	28·5	22·5	
1840.	Arrow......	$\frac{3}{4}$-inch lap to valve....	32·4		
	Rapid	1-inch ditto......	28·6		

TABLE II.

	Gross consumption of coke per mile.
Average consumption of the Company's engines in the summer of 1839. Old valve	49 lbs.
Average consumption of the Company's engines after the introduction of new mode of coke deliveries. Old valve	40 lbs.
Valves with $\frac{3}{8}$ths of an inch lap	36 lbs.

TABLE II. (*continued.*)

	Gross consumption of coke per mile.
Valves with $\frac{3}{4}$ths of an inch lap	32 lbs.
Valves with 1-inch lap, as applied to the old steam and exhausting passages, .	28 lbs.
Same valves and same engines, but with increased care in firing, so as to avoid all unnecessary waste of fuel, ...	22 lbs.
Valves with 1-inch lap, as applied to new engines with enlarged exhausting passages, larger tubes, and closer fire-bars, and greater accuracy of construction, ...	15 lbs.

The following Tables give a general summary of the work done, coke consumed, and loads conveyed by the several classes of engines, for four years.

TABLE III.

GROSS CONSUMPTION OF COKE.

	PASSENGER ENGINES.		COKE. Tons.	cwt.	qrs.	lbs. ℔ mile.	
Half-year ending June, 1840	3463 trips,	30 miles,	1523	16	3	= 32·9	Average loads, 7 coaches.
December, ,,	3596	,, ,,	1276	9	1	= 26·5	
June, 1841	3493	,, ,,	1036	15	3	= 22·1	
December, ,,	3496	,, ,,	958	19	0	= 20·5	
June, 1842	3655	,, ,,	853	3	3	= 17·4	
December, ,,	3526	,, ,,	684	9	2	= 14·5	
June, 1843	3243	,, ,,	646	1	1	= 14·9	
December, ,,	3555	,, ,,	717	2	2	= 15·1	
June, 1844	3455	,, ,,	722	18	3	= 15·6	
December, ,,	3786	,, ,,	901	6	1	= 17·8	
June, 1845	5338	,, ,,	1292	15	0	= 18·1	

	LUGGAGE ENGINES.		Tons.	cwt.	qrs.	lbs. ℔ mile.	
Half-year ending June, 1840	1925 trips,	30 miles,	1160	12	3	= 45·0	Average loads, 22 waggons, =110 tons gross, exclusive of engine and tender.
December, ,,	1653	,, ,,	867	9	3	= 39·2	
June, 1841	1640	,, ,,	749	0	1	= 34·1	
December, ,,	1370	,, ,,	531	17	1	= 29·0	
June, 1842	1604	,, ,,	559	2	2	= 26·0	
December, ,,	1521	,, ,,	421	17	2	= 20·7	
June, 1843	1588	,, ,,	441	7	2	= 20·7	
December, ,,	1605	,, ,,	451	12	2	= 21·0	
June, 1844	1576	,, ,,	492	12	2	= 23·3	
December, ,,	1630	,, ,,	539	1	1	= 24·7	
June, 1845	1799	,, ,,	596	6	1	= 24·7	

TABLE III. (*continued.*)

BANK ENGINES.

			COKE. Tons.	cwt.	qrs.
Half-year ending June,	1840	349 days,	486	11	3
December,	,,	$356\frac{1}{4}$,,	369	10	0
June,	1841	$349\frac{1}{2}$,,	343	3	2
December,	,,	$341\frac{3}{4}$,,	251	11	0
June,	1842	361 ,,	174	6	3
December,	,,	$363\frac{1}{2}$,,	143	13	3
June,	1843	$452\frac{1}{4}$,,	162	8	3
December,	,,	$517\frac{3}{4}$,,	183	12	2
June,	1844	453 ,,	183	5	0
December,	,,	485 ,,	219	12	2
June,	1845	477 ,,	210	16	1

COAL AND BALLAST ENGINES.

			Tons.	cwt.	qrs.
Half-year ending June,	1840	$436\frac{1}{4}$ days,	489	4	0
December,	,,	370 ,,	344	17	3
June,	1841	334 ,,	325	4	2
December,	,,	$351\frac{3}{4}$,,	312	4	2
June,	1842	407 ,,	313	3	2
December,	,,	$443\frac{3}{4}$,,	243	3	3
June,	1843	$306\frac{1}{2}$,,	226	5	0
December,	,,	$398\frac{1}{4}$,,	274	13	0
June,	1844	386 ,,	276	18	3
December,	,,	639 ,,	484	2	2
June,	1845	776 ,,	660	11	1

Average load, 15 waggons.

TABLE IV.

GENERAL RESULT.

In the year 1838	12604 tons of coke consumed.	
1839	11754 ,, ,,	
1840	6518 ,, ,,	
1841	4508 ,, ,,	
1842	3393 ,, ,,	
1843	3103 ,, ,,	
1844	3819 ,, ,,	In this year the mileage was materially increased.

CONCLUSION.

The principles set forth in this Paper have a *general* application to steam engines of every form, to the condensing as well as the non-condensing, to the fixed as well as to the locomotive.

A personal knowledge of many facts connected with the history and development

of the locomotive engine upon the first field of its application to the transport of passengers and merchandise at high velocities,—the Liverpool and Manchester Railway,—has induced the writer to refer more frequently to the instance of the locomotive than to that of the fixed engine, for the purpose of illustrating his positions.

Nevertheless, the history of any one species of steam engine is in many respects the type of the history of the rest. There is observable in all, the same progress from imperfect and crude forms to those of a more advanced state of perfection; the same alternations of failure and success equally leading to the attainment of some fresh starting-point from whence a renewed extension of effort becomes possible.

The same agencies at work in one are at work in all. The source of heat is the same,—the means of transposing the heat into motive force are the same. Whatever differences in the results are found, may be referred to some peculiarity in the construction of the vessels or apparatus, or in the manipulation of them, by which more or less of the heat produced and motive force generated can be effectively applied to the wants of man.

Such differences of results admit of being accounted for and explained. Some will be found to arise from an essential difference in the principle of the engine, as in comparing the non-condensing with the condensing engine, or the condensing-inexpansive with the condensing-expansive engine. Some may arise from differences in the construction of subordinate parts, altogether irrespective of the want of conformity in principle, and which may therefore be considered in nowise incidental to the particular principle involved. Some again may depend on the amount of care and attention exercised by the parties in charge.

In the former case, nothing can be done by way of improvement without encountering as an obstacle the very principle of the engine itself.

In the latter cases, the remedy is found by applying in one instance what has been already applied advantageously in another.

No doubt, there remains yet great space for improvement in all classes of engines, both as respects principle and the methods of carrying out the principle; but at the same time there is the strongest ground for the belief, not only that the reduced performances of engines of the same class differ greatly from each other, but also that those of engines of different classes, when compared together, and due allowance made for difference of principle, are by no means in agreement.

Whilst this state of things continues, there is margin enough for improvement by attending to *methods* of working, without even touching the *principle;* and to this end it is only necessary that every owner of a steam engine, every one, in fact, who is interested in its economy, should make himself master of two sets of

facts: 1st, the knowledge of the actual duty performed by his own engine; and 2ndly, the knowledge of what has been performed in similar engines, and of what therefore *may* be performed in his own. This comparison of duty would at once point to the advantages he may secure, and lead to obtaining them.

If, for instance, a certain class of boilers, known under the designation of Cornish boilers, but distinguished from other classes of modern boilers only or chiefly by the addition of such simple appliances as may serve to prevent undue dissipation of heat, has been found to evaporate considerably more water by a given weight of fuel than other descriptions of boiler, in which such appliances are not found, the inference is obvious, that what has been done in the one case may be equally done in the other. And if the Cornish engine, by the aid of its peculiar construction of boiler, and mode of firing, combined with the application of high-pressure steam and expansive working, has accomplished with 3 or 4 ℔s. of coal what the ordinary Boulton and Watt factory engine does with 10 ℔s., further progress may doubtless be made towards economy of fuel in the fixed engines of our manufacturing districts.

According to the returns quoted by Mr. Parkes, and heretofore cited, the best Boulton and Watt non-expansive condensing engines raise between 28,000 and 29,000 ℔s. 1 foot by 1 ℔. of steam.

According to Mr. Armstrong, who has much experience in the working of the engines in and around Manchester, those engines consume 10 ℔s. of coal per horse-power per hour, after deducting for various causes of waste and loss. This is a duty of 218,000 ℔s. raised 1 foot by 1 ℔. of coal; and assuming 1 ℔. of coal to evaporate 6 ℔s. of water, the engines raise 33,000 ℔s. 1 foot high by 1 ℔. of steam; a result rather better than that given by Mr. Parkes.

However paradoxical the statement may appear, the average performances of good locomotive engines which do *not condense* their steam are absolutely greater than those recorded of the Boulton and Watt *condensing* factory engines, notwithstanding the disadvantages under which the locomotive has been supposed to lie from its greatly inferior size of boiler,—from the great intensity of fire and rapidity of combustion,—from the necessity of procuring the draft by mechanical means,—and from the general exposure of its surface on every side to the cooling influence of the atmosphere.

In the year 1843, the average *gross* consumption of coke in luggage trains, (see Table,) with average loads of 20 waggons, or 100 tons, was 20 ℔s. per mile. Adding to this weight that of the engine and tender, say 20 tons, the gross load kept in motion by 20 ℔s. of coke per mile (or less, allowing for waste) was 120 tons.

If the sum of all resistances, whether arising from friction or from the action

of the air on the surface of the train, but not including the atmospheric pressure against the pistons, or even the force expended on the blast, be taken at 8 lbs. per ton, the estimate must be considered a very low one.

Then the resistance of the entire train is

$$120 \text{ tons} \times 8 \text{lbs.} = 960 \text{ lbs.}$$

Therefore the effect of the 20 lbs. of coke is 960 lbs. raised 1 mile or 5280 feet, equal to

$$5,068,800 \text{ lbs. raised 1 foot;}$$

and the useful effect of 1 lb. *of coke* is

$$5,068,800 \div 20 \text{ lbs.} = 253,440 \text{ lbs. raised 1 foot.}$$

As 1 lb. of coke evaporates $7\frac{1}{2}$ lbs. water,[13] the effect of 1 lb. *of water* is

$$253,440 \text{ lbs.} \div 7\tfrac{1}{2} = 33,792 \text{ lbs. raised 1 foot.}$$

When it is considered that a pound of coke burnt in a locomotive engine whose boiler has hitherto been unjustly considered to belong to the most extravagant class, actually accomplishes as much as one pound of coal in the best reported Boulton and Watt non-expansive condensing engines, and more than twice as much as the same weight of coal in the best high-pressure stationary engines, it will appear reasonable to admit that there exists great room for improvement in most stationary engines.

Doubtless, also, there are great disparities in the work of individual engines of the same class, and of the same engine at different times, whether fixed or locomotive. These can only be reduced by the check of constant and close supervision, and an accurate appreciation of the causes which produce them.

[13] From a temperature of say 50°.

Old Valve 1/16th lap.

Fig. 1.
oke commences.

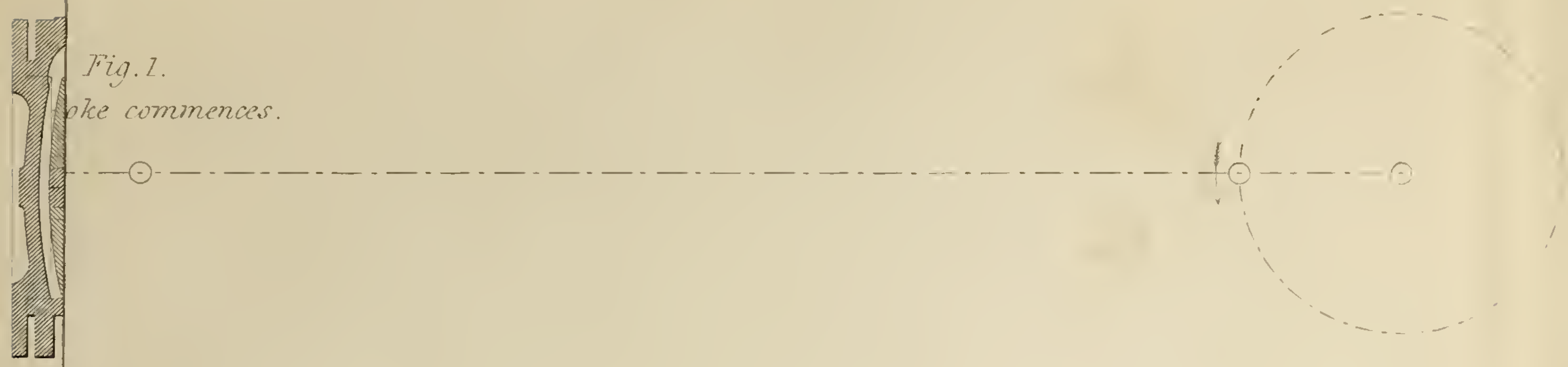


Fig. 2.
am port open.

Fig. 3.
am port open.

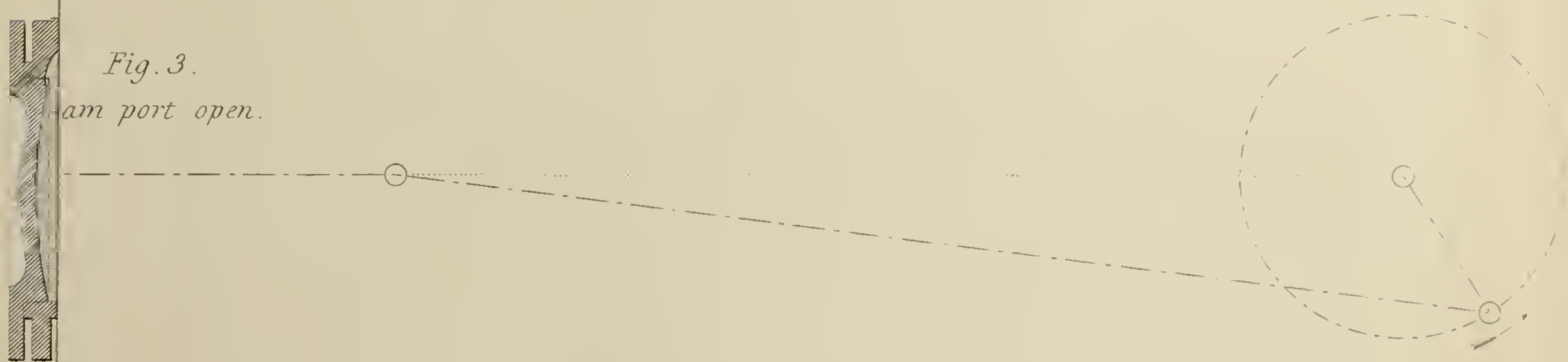


Fig. 4.
eam port open.

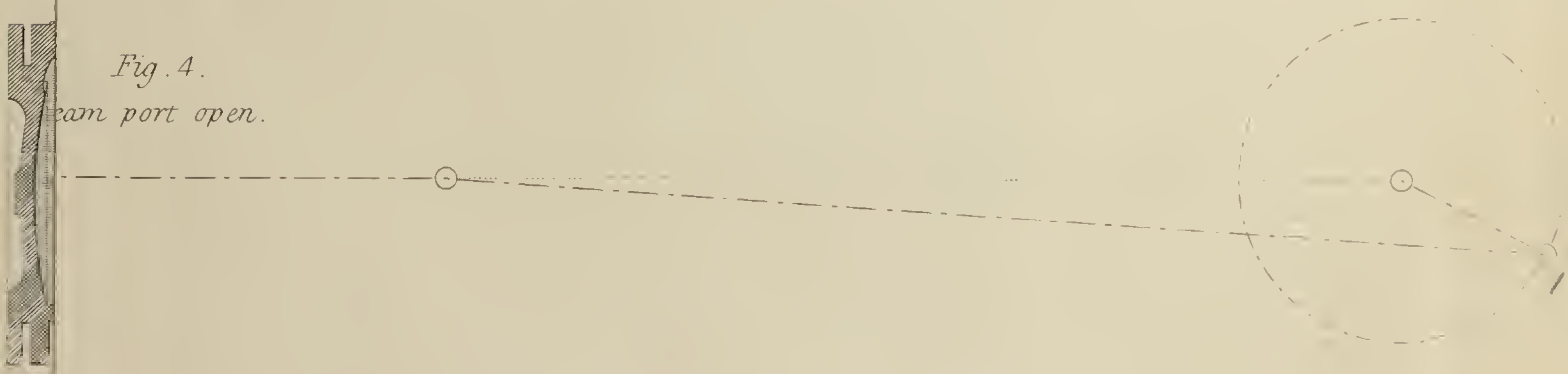
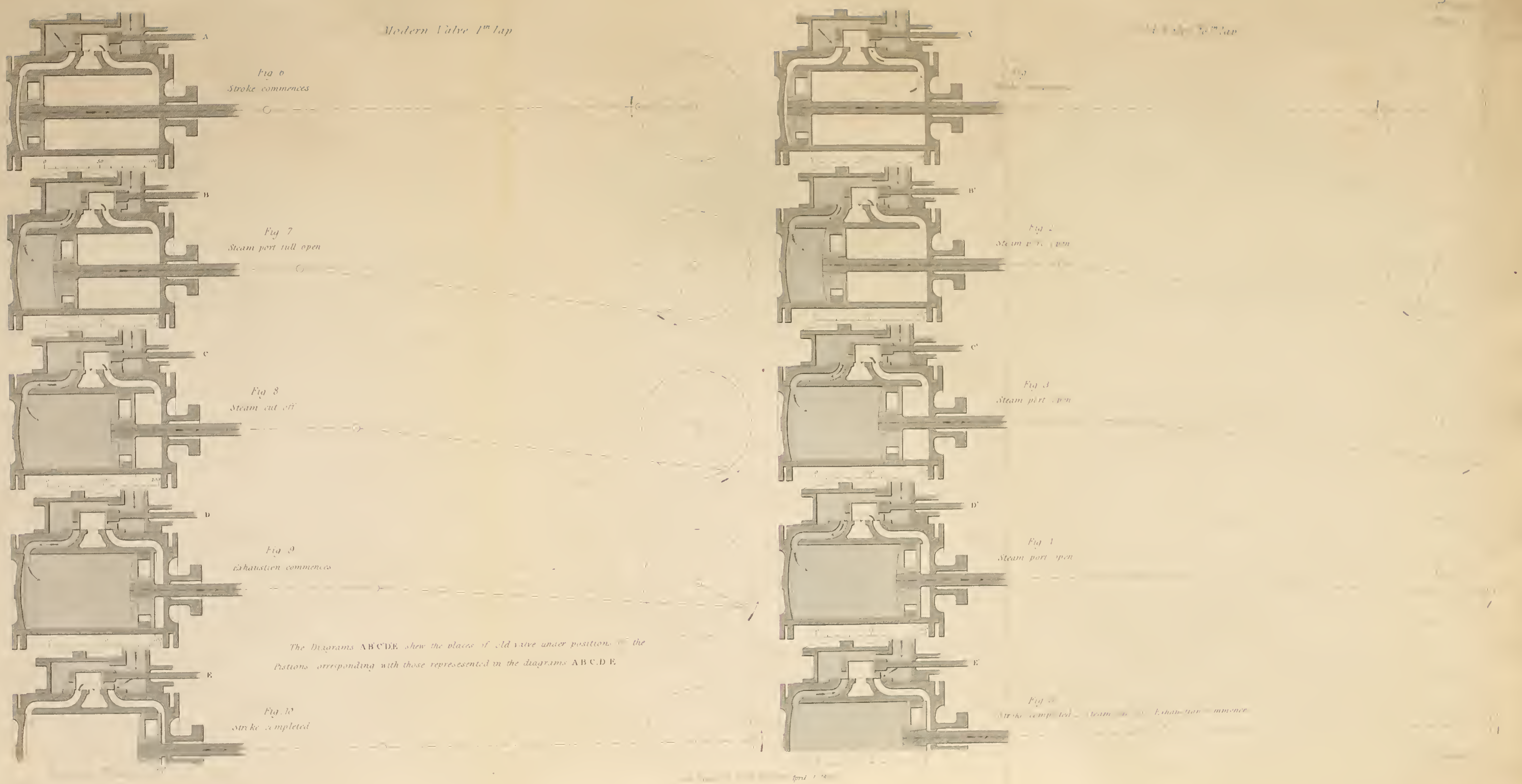
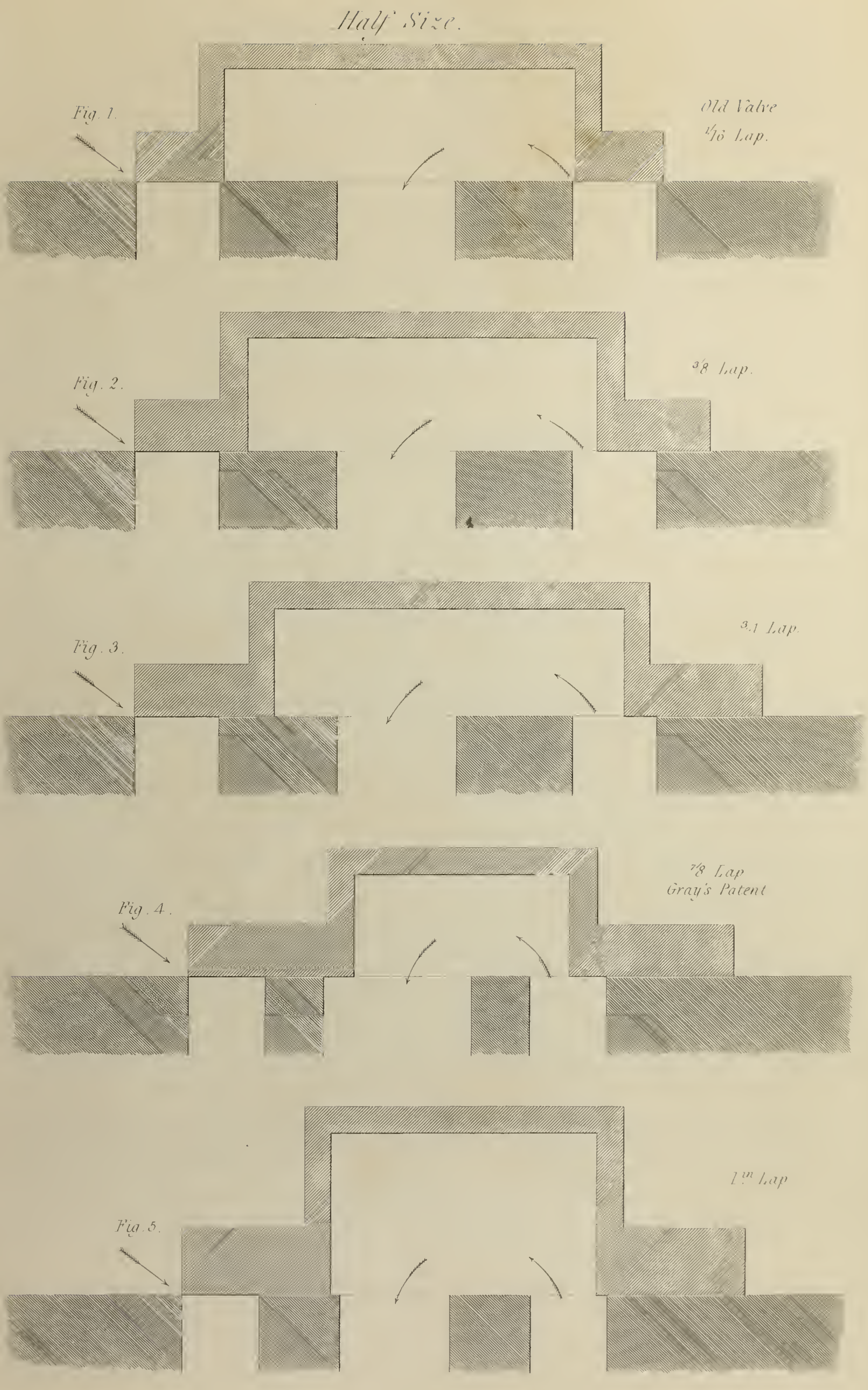


Fig. 5.
oke completed „ Steam cut off „ Exhaustion commences.


Modern Valve 1in lap
A
Fig 6
Stroke commences
B
Fig 7
Steam port full open
C
Fig 8
Steam cut off
D
Fig 9
Exhaustion commences
E
Fig 10
Stroke completed
The Diagrams A'B'C'D'E' shew the places of old valve under positions of the
Pistons corresponding with those represented in the diagrams A B C D E
B'
C'
D'
E'



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